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AFAPL ltr dtd 12 Apr 1972

AFAPL-TR-67-114
Part III, Volume II

VAPORIZING AND ENDOTHERMIC FUELS FOR ADVANCED ENGINE APPLICATION

Part III. Studies of Thermal and Catalytic Reactions, Thermal Stabilities, and Combustion Properties of Hydrocarbon Fuels

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Shell Development Company,
A Division of Shell Oil Company

TECHNICAL REPORT AFAPL-TR-67-114, Part III, Volume II

February 1970

Air Force Aero Propulsion Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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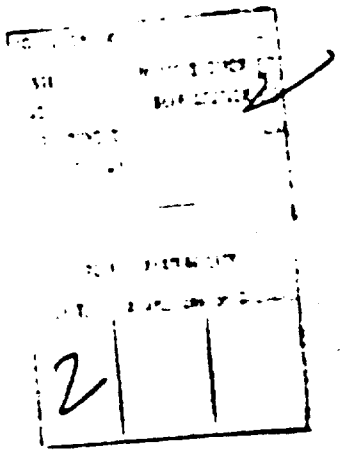

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Calculation Procedure for Mach 8 Engine

Station 1.

Use the following formulas from Ref. 12 to calculate the inlet area:

$$I_f = \frac{\eta_e (H_f) J}{V_1}$$

$$W_f = \frac{\eta_n (F_g)}{I_f}$$

$$A_1 = \frac{W_f}{(F/A)(\rho_1)(V_1)}$$

Assume: $\eta_e = .412$

$\eta_n = .95$

$H_f = 18894$ Btu/lbm fuel

At 100,000 ft and M = 8

$T_1 = 420.1°R$

$P_1 = 22.32$ lb/ft^2

$\rho_1 = .000996$ lbm/ft^3

$V_1 = 8050.96$ ft/sec

$$I_f = \frac{(.412)(18894)(778)}{(8051)}$$

$I_f = 752.23$ sec

Assume: $L/D = 6$

$L = 450{,}000$ lb

$D = F_g = 75000$ lb

Therefore:

$$W_f = \frac{(.95)(75000)}{752.23}$$

$W_f = 94.72$ lbm/sec fuel

To Calculate the stoichiometric fuel-air ratio (F/A) assume the fuel is MCH converted to H_2 and C_7H_8:

$$.75\ H_2 + .25\ C_7H_8 + 2.625\ O_2 + 2.625(3.76)N_2 \rightarrow$$

$$1.75\ H_2O + 1.75\ CO_2 + 9.87\ N_2$$

The average molecular weight of the fuel: 25.25

$$F/A = \frac{(1 \text{ mole of fuel})(25.25 \text{ lbm molecular weight})}{(9.87 + 2.625 \text{ moles air})(28.95 \text{ lbm molecular weight})}$$

$$\boxed{F/A = .0698} \quad \text{Assuming E.R} = 1.0$$

$$A_1 = \frac{24.72}{(.0698)(.000996)(5051)}$$

$$\boxed{A_1 = 169.23 \text{ ft}^2}$$

Station 3.

Use the Dugger Equation for the total pressure drop from Station 1 to 3:

$$\eta_d = 1 - \frac{\left(\frac{P_{t_1}}{P_{t_3}}\right)^{\bar{\gamma}-1/\bar{\gamma}} - 1}{[(\bar{\gamma} - 1)/2]M_1^2}$$

Assume: $\eta_d = .959$

$\bar{\gamma} = 1.4$

then

$$\frac{\bar{\gamma} - 1}{\bar{\gamma}} = \frac{1.4 - 1}{1.4} = .286$$

$$\frac{\left(P_{t_1}/P_{t_3}\right)^{.286} - 1}{((1.4 - 1)/2)(8)^2} = 1 - .959$$

$$\left(P_{t_1}/P_{t_3}\right)^{.286} = 1.5248$$

$$\left(P_{t_1}/P_{t_3}\right) = 4.36$$

From the isentropic flow tables at M = 8

$$P_1/P_{t_1} = .000102$$

$$P_{t_1} = \frac{22.32 \text{ lb/ft}^2}{(.000102)(144 \text{ in}^2/\text{ft}^2)}$$

$$P_{t_1} = 1519 \text{ lb/in}^2$$

$$P_{t_3} = \frac{1510 \text{ lb/in}^2}{4.30}$$

$$P_{t_3} = 348 \text{ lb/in}^2$$

Assume:

$\boxed{M_3 = 2.5}$ then

From the isentropic flow tables at M = 2.5

$$P_3/P_{t_3} = .05853$$

$$\boxed{P_3 = 20.4 \text{ lb/in}^2}$$

Assume the enthalpy at 1 and 3 are equal:

$$h_{t_1} = h_{t_3} = h_3 + \frac{(M_3\ 49.1\sqrt{T_3})^2}{2g_c J}$$

$$h_{t_1} = 100.32 + \frac{\left((8)(49.1)\sqrt{420.1}\right)^2}{(2)(32.2)(778)}$$

$$h_{t_1} = 1394 \text{ Btu/lbm}$$

By trial and error $\boxed{T_3 = 2500°R}$

$$h_{t_3} = 732.33 + \frac{\left((2.5)49.1\sqrt{2500}\right)^2}{(2)(32.2)(778)}$$

$\underline{h_{t_3} = 1395}$ close enough

$$\rho_3 = \frac{(20.4)(144)}{(53.34)(2500)}$$

$\underline{\rho_3 = .0220 \text{ lbm/ft}^3}$

Station 5.

By an iterative procedure calculate the heat transfer from the combustion area assuming 2000°R wall temperature and thus the total temperature rise. Then using a Rayleigh line relationship the remaining conditions at Station 5 may be determined.

First calculate the flow area and heat transfer area:

$$\dot{m} = \rho_3 A_3 V_3 = \rho_1 A_1 V_1$$

$$V_3 = (2.5)(49.1)\sqrt{2500}$$

$$V_3 = 6140$$

$$A_3 = \frac{\rho_1 A_1 V_1}{\rho_3 V_3} = \frac{(.000006)(169)(8051)}{(.0220)(6140)}$$

$$\boxed{A_3 = 10.0} \qquad 10.0 = \pi r_1^2 - \pi r_3^2 = 169 - \pi r_3^2$$

$$r_3 = 7.11 \text{ ft}$$

Hydraulic Diameter D_h

$$D_h = \frac{4A_3}{P_w} = \frac{4(10.0)}{2\pi(7.11) + 2\pi(7.28)}$$

$$\underline{D_h = .444}$$

Assume time for combustion and mixing can be accomplished in 2 μsec = .002 sec and the average velocity in the combustor is 5000 ft/sec.
The length of the combustor then is L

$$L = (.002)(5000)$$

$$\boxed{L = 10 \text{ ft}}$$

Forming a heat balance on the combustion area

$$(h_p' - h_{P_o}') - (h_R' - h_{R_o}') - q = -h_{RP_o}$$

where: h_R' = enthalpy of the reactants
h_p' = enthalpy of the products
h_{RP_o} = heat of combustion
q = heat transferred per lbm fuel

Heat of combustion calculation:

$$h_{RP_o} = m_{C_7H_8}(h_{RP_o})_{C_7H_8} + m_{H_2}(h_{RP_o})_{H_2}$$

$$m_{C_7H_8} = .938 \text{ lbm } C_7H_8/\text{lbm fuel}$$

$$m_{H_2} = .062 \text{ lbm } H_2/\text{lbm fuel}$$

$(h_{RP_o})_{C_7H_8} = -17601$ Btu/lbm

$(h_{RP_o})_{C_7H_8} = -51593$ Btu/lbm

$h_{RP_o} = (.938)(-17601) + (.062)(-51593)$

$\underline{h_{RP_o} = -19708.5 \text{ Btu/lbm fuel}}$

The reactants:

$$h_R' - h_{R_o}' = (h' - h_o')_{air} + (h' - h_o')_{fuel}$$

$$(h' - h_o')_{air} = n_{air} \frac{M_{air}}{M_{fuel}} (h_{2500} - h_{537})$$

$$= \frac{(2.625 + 9.87)\ 28.95}{25.25} (645.78 - 128.34)$$

$\underline{(h' - h_o')_{air} = 7412.8 \text{ Btu/lbm fuel}}$

$$(h' - h_o')_{fuel} = c_{P_{fuel}}(t - t_o)$$

Assume: $c_{P_{fuel}} = .766$ Btu/lbm - °F

$t = 900$ °F

$(h' - h_o')_{fuel} = (.766)(900 - 77)$

$(h' - h_o')_{fuel} = 631$ Btu/lbm fuel

$\underline{h_R' - h_{R_o}' = 8043.8 \text{ Btu/lbm fuel}}$

The products:

Calculate enthalpy of products as function of temperature and make plot.

Constituent	n	$\bar{h}_{537}$	$\bar{h}_{4000}$	$n\Delta h$	$\bar{h}_{5000}$	$n\Delta h$	$\bar{h}_{2360}$	$n\Delta h$
CO_2	1.75	4030	49231	79102	64000	104948	69677	114881
H_2O	1.75	4258	40489	63404	53327	85871	58339	94991
N_2	9.87	3730	31329	272406	40080	358773	43436	391898
				414913		549591		601771

$$(hp' - hp_o')_t = \frac{n\Delta h}{M_f} = \frac{n\Delta h}{25.25}$$

Temp, °R	$(h_{P'} - h_{P_C'})_t$ Btu/lbm Fuel
4000	16432
5000	21766
5380	23833

} See plot on following page (Figure 72)

Estimate of Heat Transfer From the Combustor:

Procedure:

1. Assume Temperature at Station 5
2. Calculate Mach Number and pressure at Station 5 from Rayleigh line
3. Assume linear variation of pressure and temperature over length of combustor
4. Calculate density, velocity, viscosity, Reynolds Number, Nusselt Number, correction constant for high velocity heat transfer, thermal conductivity, heat transfer coefficient, adiabatic wall temperature and the final product, $hP\Delta t$, where P is the wetted perimeter, $\Delta t = t_{Aw} - t_w$ and $t_w = 2000°R$, and h is the local heat transfer coefficient.
5. From curve of $hP\Delta t$ vs x calculate heat transferred;

$$q = -\int_{x=0}^{x=L} hP\Delta t\,dx$$

6. From q and $(h' - h_o')_P$, $(h' - h_o')_R$ and h_{RP_o} calculate temperature at Station 5.
7. Return to 2 until temperature used to calculate values and calculated temperature are equal.

Example:
Station 3:

M = 2.5

P = 20.4

T = 2500°R

(P/P^*) = .24616

(T/T^*) = .3787

Assume T_3 = 5637.5°R

$$(T/T_\infty)_3 = (T/T_\infty)_3 \, T_3/T_3 = (.3787) \frac{(5637.5)}{(2500.)}$$

$$(T/T_\infty)_3 = .8540$$

From Rayleigh Line:

$M_3 = 1.31$

$(P/P_\infty)_3 = .70535$

$P_3 = (P/P_\infty)_3/(P/P_\infty)_3 \, P_3 = (.70535)/(.24616)\ (20.4$

$P_3 = 58.45$ lb/in^2

x	P	T	ρ	V	μ x 10^{-3}	Re x 10^6	Nu_1 (M=0)	M	c	Nu	k
0	20.4	2500	.022	6150	3.4	1.76	1330	2.50	.65	864.5	.048
2	26.0	3110	.024	5633	3.8	1.58	1270	2.06	.75	952.5	.056
4	35.6	3740	.026	5200	4.2	1.43	1220	1.73	.81	988.2	.062
6	43.3	4370	.027	5007	4.6	1.30	1170	1.54	.84	982.8	.0685
8	51.0	5000	.028	4872	4.9	1.24	1145	1.40	.88	1007.6	.074
10	58.45	5637.5	.028	4828	5.2*	1.17	1110	1.31	.89	987.9	.079*

* Extrapolated (based on air at low pressures)

x	Pr	Pr 1/3	T_{AW}/T	T_{AW}	Δt	h	hPΔt
0	.73	.90	2.125	5312.5	3312.5	93.4	2.80 x 10^7
2	.75	.91	1.77	5504.7	3504.7	120.1	3.81 x 10^7
4	.79	.92	1.55	5797.0	3797.0	138.0	4.74 x 10^7
6	.90	1.0	1.47	6423.9	4423.9	151.6	6.07 x 10^7
8	1.00	1.0	1.39	6950.0	4950.0	167.9	7.52 x 10^7
10	1.00	1.0	1.34	7554.3	5554.3	175.8	8.84 x 10^7

In the above calculations the following expression were used:

$\rho = P/RT$ where R = 53.34

$V = \rho_1 V_1/\rho = 135.2/\rho$

$$Re = \frac{V D_h \rho}{\mu}$$

$Nu_1 = f(Re, Pr)$ from Kays[14] expression for turbulent flow inside concentric annulli at $r_i/r_o = 1.0$ (See Figure 73)

$M = V/(49.1\sqrt{T})$

C = From Kays page 13.38 for affect of high velocity on Stanton No.

$$Nu = CNu_1$$

$$h = \frac{Nuk}{D_h}$$

$$T_{AW}/T = 1 + \frac{Pr^{1/3}}{2}(\gamma - 1)M^2 \qquad \text{where } \gamma = 1.4$$

$$\Delta t = (T_{AW} - T_W) = (T_{AW} - 2000)$$

$$P = 2\pi r_i + 2\pi r_o = 90.5 \text{ ft}$$

Then: $q' = -\int_{x=0}^{x=L} (hP\Delta t)_x \, dx$ This is expression is integrated graphically from Figure 74

$$q' = -5.575 \times 10^8 \text{ Btu/hr}$$

$$\dot{m}_{air} = \rho_1 A_1 V_1 = 4.879 \times 10^6 \text{ lbm/hr}$$

$$q = -\frac{5.575 \times 10^8}{4.879 \times 10^6}$$

$$q = -1.1426 \times 10^2 \text{ Btu/lbm air}$$

$$q' = -\frac{1.1426 \times 10^2}{.0698}$$

$$\underline{q' = -1637 \text{ Btu/lbm fuel}}$$

Now to calculate the combustion temperature:

$$(h' - h_o')_P - (h' - h_o')_R - q' = -h_{RP_o}$$

$$(h' - h_o')_P - 8043.8 + 1637 = -(-19708.5)$$

$$\therefore (h' - h_o)_P = 26115.3 \text{ Btu/lbm fuel}$$

From curve in Figure 75 this gives a temperature:

$T_s = 5800°R$ which does not agree with assume temp, $\therefore$ recalculate

However, by plotting the calculated temperatures vs the assumed temperatures we can find the point they are equal. In addition by plotting the heat transferred vs the assumed temperature we can obtain the actual heat transfer at the actual temperature - see curves in Figure 75.

This yields:

$T_s = 5791°R$
$q' = 1727$ Btu/lbm fuel

Then $(T/T^*)_5 = (.3787)\frac{(5791)}{(2500)}$

$(T/T^*)_5 = .8774$ from Rayleigh line we get

$\boxed{M_5 = 1.265}$

$(P/P^*)_5 = .740$

$P_5 = \frac{(.740)}{(.24616)}$ (20.4

$\boxed{P_5 = 61.3 \text{ lb/in}^2}$

Station 6.

Assume: 1. Isentropic expansion from 5 to 6.
2. $A_6 = 313.58 \text{ ft}^2$ (D = 20 ft)

$(A/A^*)_6 = (A/A^*)_5 \frac{A_6}{A_5} = \frac{(1.052)(313.58)}{10.0}$

$(A/A^*)_6 = 32.89$

$\boxed{M_6 = 5.28}$

$(P/P_0)_6 = .001538$

$P_6 = \frac{(.001538)(61.3)}{.377}$

$\boxed{P_6 = .250 \text{ lb/in}^2}$

$T_6 = \frac{(T/T_0)_6}{(T/T_0)_5} T_5$

$T_6 = \frac{(.15415)(5791)}{.758}$

$\boxed{T_6 = 1177.88^\circ R}$

$V = (5.28)(49.1)\sqrt{1177.88}$

$V_6 = 8897.48 \text{ ft/sec}$

$$\rho_e = \frac{36.05}{(53.34)(1177.88)}$$

$$\underline{\rho_e = .000574 \text{ lbm/ft}^3}$$

Calculate Thrust, Specific Impulse, and Overall Efficiency:

Thrust = $F_g = f_e - f_i - P_i(A_e - A_i)$

$$f_e = A_e\left(P_e + n_n \frac{\rho_e V_e^2}{g_c}\right)$$

$$f_i = A_i\left(P_i + \frac{\rho_i V_i^2}{g_c}\right)$$

$$n_n = .95$$

} From Rugger[12])

$$f_i = 169\left(22.32 + \frac{(.000996)(8051)^2}{32.2}\right)$$

$$\underline{f_i = 342644.1 \text{ lb}}$$

$$f_e = 313.58\left(36.05 + \frac{.95(.000574)(8897.48)^2}{32.2}\right)$$

$$\underline{f_e = 431703.9 \text{ lb}}$$

$$F_g = 431703.9 - 342644.1 - 22.32(313.58 - 169.)$$

$$\boxed{F_g = 85833.22 \text{ lb}}$$

Specific Impulse:

$$I_f = \frac{n_n(F_g)}{W_f}$$

$$W_f = f_{o_i} V_i A_i = (.0698)(.000996)(169.)(8051)$$

$$W_f = 94.6 \text{ lbm/sec fuel}$$

$$I_f = \frac{(.95)(85833.22)}{94.6}$$

$$\boxed{I_f = 861.96 \text{ sec}}$$

Overall Efficiency:

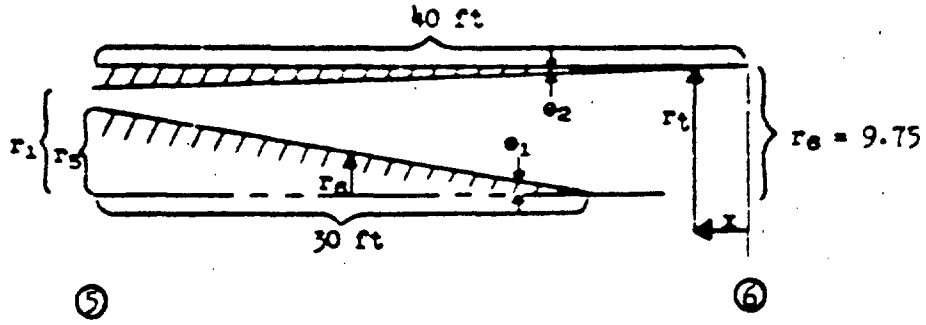
$$n_o = \frac{I_f V_i}{H_f + V_i^2/2g_c J}$$

$$n_e = \frac{(861.96(8050.96)}{\left(19708.5 + \frac{(8050.96)^2}{(2)(32.2)(778)}\right) 778}$$

$$\boxed{n_e = .4247}$$

Estimate of Heat Transfer From Nozzle:

Consider the nozzle below: (Note: the values below are not the final but a first estimate)



Flow Area:

$r_e - r_1 = 9.75 - 7.28 = 2.47$

$\tan \theta_2 = \frac{2.47}{40} = .06175$ $\qquad$ $\tan \theta_1 = \frac{7.11}{30.0} = .237$

$\theta_2 = 3\frac{1}{2}°$

From x = 0 to x = 10 where $r_t = r_e - x \tan \theta_2 = 9.75 - x\ (.06175)$

From x = 10 to x = 40 $A_x = \underbrace{\pi r_t^2}_{A_t} - \underbrace{\pi r_b^2}_{A_b}$ $\qquad$ $r_b = (x - 10) \tan \theta_1 = (x - 10).237$

$x' = 40 - x$

x'	x	r_t	A_t	r_b	A_b	A_x
40	0	9.75	298.8	0	0	298.8
30	10	9.13	262.0	0	0	262.0
20	20	8.52	227.8	2.37	17.6	210.2
10	30	7.90	195.9	4.74	70.6	125.3
5	35	7.60	180.9	5.92	110.3	70.6
4	36	7.53	178.0	6.16	119.3	58.7
3	37	7.47	175.1	6.40	128.6	46.5
2	38	7.40	172.2	6.64	138.3	33.9
1	39	7.34	169.3	6.87	148.4	20.9

Assuming isentropic expansion to each point:

$$(A/A^*)_x = \frac{(A/A^*)_s A_x}{A_s} = \frac{1.1}{10.3} = .10967\ A_x \quad (ft^2)$$

This yields a Mach Number from Isentropic Flow Tables.

$$T_x = \frac{(T/T_o)_x}{(T/T_o)_s} T_s = \frac{(T/T_o)_x\ 5465}{.726} = 7527.5\ (T/T_o)_x \quad (°R)$$

$$P_x = \frac{(P/P_o)_x}{(P/P_o)_s} P_s = \frac{(P/P_o)_x\ 54}{.323} = 167\ (P/P_o)_x \quad (lb/in^2)$$

$$V_x = M_x 49.1\sqrt{T_x} \quad (ft/sec)$$

$$\rho_x = \frac{P_x\ 144}{53.34\ T_x} = 2.7\ P_x/T_x \quad (lbm/ft^3)$$

x'	$(A/A^*)_x$	M	$(P/P_o)_x$	P_x	$(T/T_o)_x$	T_x	V_x	ρ_x	μ
1	2.292	2.35	.074	12.38	.475	3525	6851	.00948	4.4×10^{-5}
2	3.718	2.86	.034	5.68	.379	2815	7451	.00544	3.93
3	5.10	3.20	.020	3.34	.328	2430	7745	.00371	3.68
4	6.44	3.45	.014	2.34	.290	2150	7855	.00294	3.47
5	7.74	3.64	.0108	1.81	.274	2063	8118	.00236	3.40
10	13.74	4.28	.0050	.836	.220	1656	8552	.00136	3.07
20	23.05	4.90	.00213	.356	.172	1294	8654	.00074	2.75
30	28.73	5.10	.00165	.276	.160	1200	8674	.00062	2.66
40	32.89	5.28	.00154	.257	.154	1160	8831	.00060	2.62

Assume the heat transfer relation is turbulent flow flat plate.

$$Nu_x = c(.332(Pr)^{1/3}(Re_x)^{1/2}) = cNu_1$$

$$Re_x = \frac{Vx'\rho}{\mu}$$

c = correction constant for high speed flow (Kays,[14] p. 13.28)

$$h = \frac{Nu_x k}{x'} \quad (Btu/hr\text{-}ft^2\text{-}°F)$$

x'	Re	$Re^{1/2}$	Pr	$Pr^{1/3}$	Nu_1	c	Nu_x	k	h
1	1.475×10^6	1.214×10^3	.83	.94	378.9	.70	265	.065	17.2
2	2.06	1.435	.76	.91	433.5	.63	273	.058	7.9
3	2.34	1.530	.74	.90	457.2	.58	265	.054	4.8

(Continued)

x'	R_e	$R_e^{1/2}$	Pr	$Pr^{1/3}$	Nu'	c	Nu_x	k	h
4	2.66	1.63	.73	.90	487.0	.55	268	.050	3.4
5	2.82	1.68	.73	.90	502.0	.54	271	.049	2.7
10	3.79	1.946	.71	.89	575.0	.45	259	.044	1.1
20	4.66	2.16	.70	.89	638.2	.38	243	.038	.46
30	6.06	2.46	.70	.89	726.9	.37	269	.037	.33
40	8.06	2.84	.696	.89	839.2	.36	302	.036	.27

$$T_{AW} = T_x\left(1 + \frac{r_c}{2}(\gamma - 1)M^2\right)$$

$$\gamma = 1.4$$

$$r_c = Pr^{1/3}$$

$$\Delta t = T_{AW} - T_W = (T_{AW} - 2000^\circ R)$$

$$P = 2\pi r_t + 2\pi r_b$$

x'	T_{AW}	Δt	P	$hP\Delta t$
1	7184.8	5184.8	89.3	7.96×10^6
2	6959.6	4959.6	88.2	3.46
3	6909.0	4909.0	87.1	2.05
4	6756.3	4756.3	86.0	1.39
5	6983.1	4983.1	84.9	1.14
10	7116.3	5116.3	79.4	.447
20	6886.4	4886.4	68.4	.154
30	6818.2	4818.2	57.4	.091
40	6981.0	4981.0	61.3	.082

Then:

$$q_N = \int_{x'=0}^{x'=40} (hP\Delta t)_x dx'$$

Integrating graphically from curve of x' vs $hP\Delta t$ in Figure 76 we get,

$$q_N = 47.8 \times 10^6 \text{ Btu/hr}$$

$$q_N = \frac{47.8 \times 10^6 \text{ Btu/hr}}{4.879 \times 10^6 \frac{\text{lbm air}}{\text{hr}}}$$

$q'_N = 9.797$ Btu/lbm air

$q'_N = \frac{9.797}{.0698}$ lbm fuel/lbm air

$\boxed{q'_N = 140.4 \text{ Btu/lbm fuel}}$

$q'_T = q'_N + q'_c$

$\boxed{q'_T = 1867.4 \text{ Btu/lbm fuel}}$

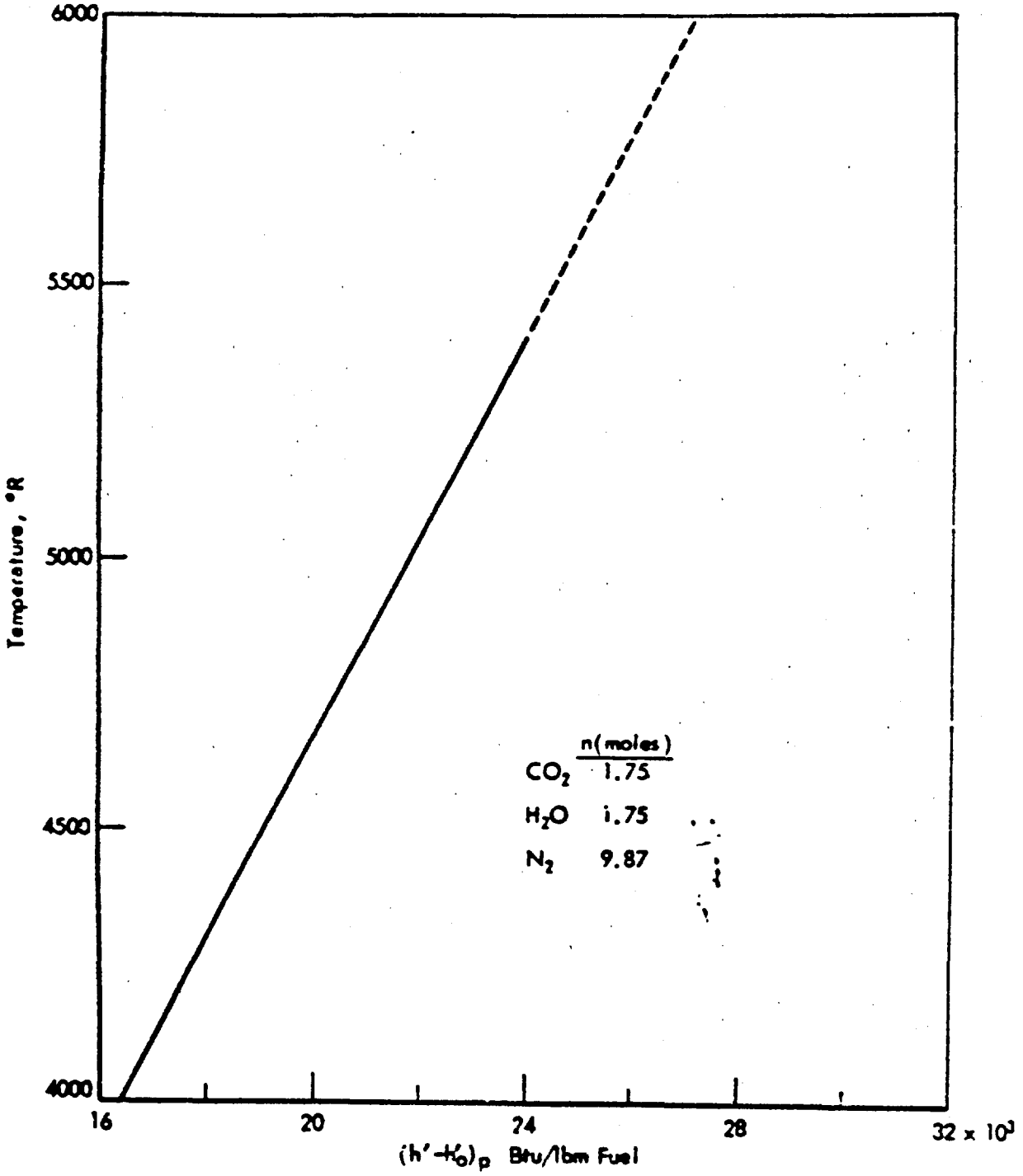


Figure 72. ENTHALPY OF PRODUCTS OF COMBUSTION

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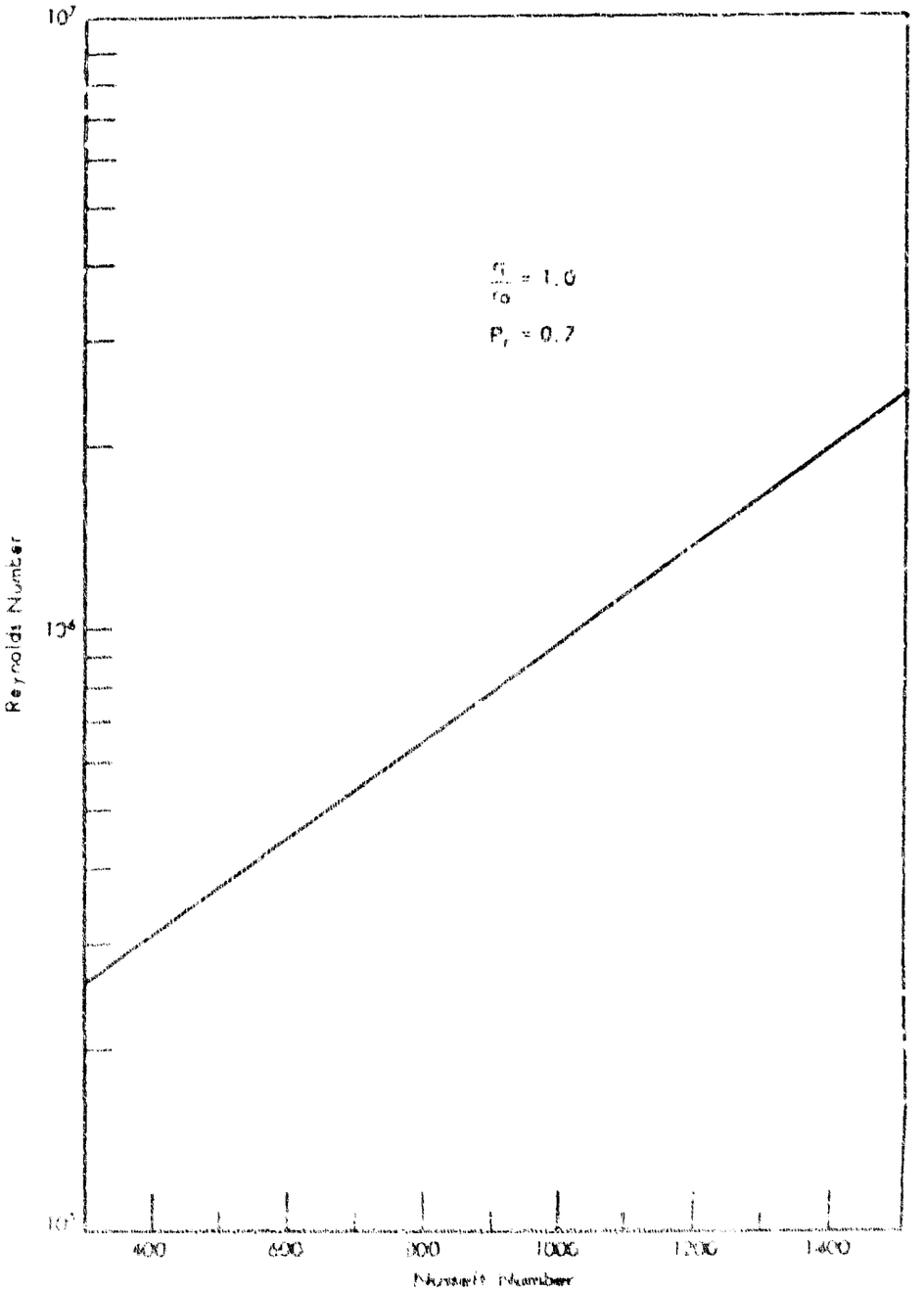


Figure 73. TURBULENT ANNULAR FLOW
From Kay, Table 9-7

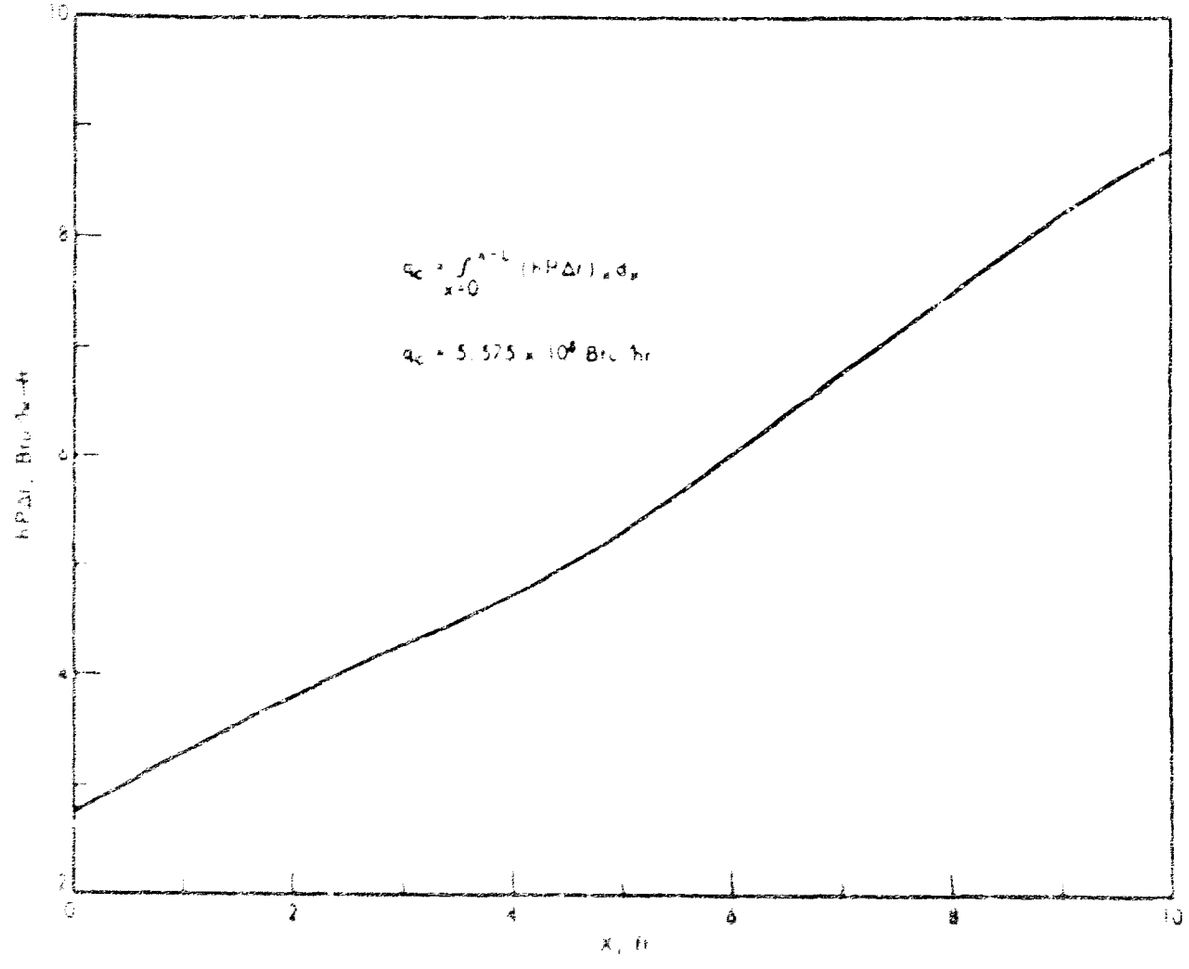


Figure 24. CONVECTIVE HEAT FLUX DISTRIBUTION

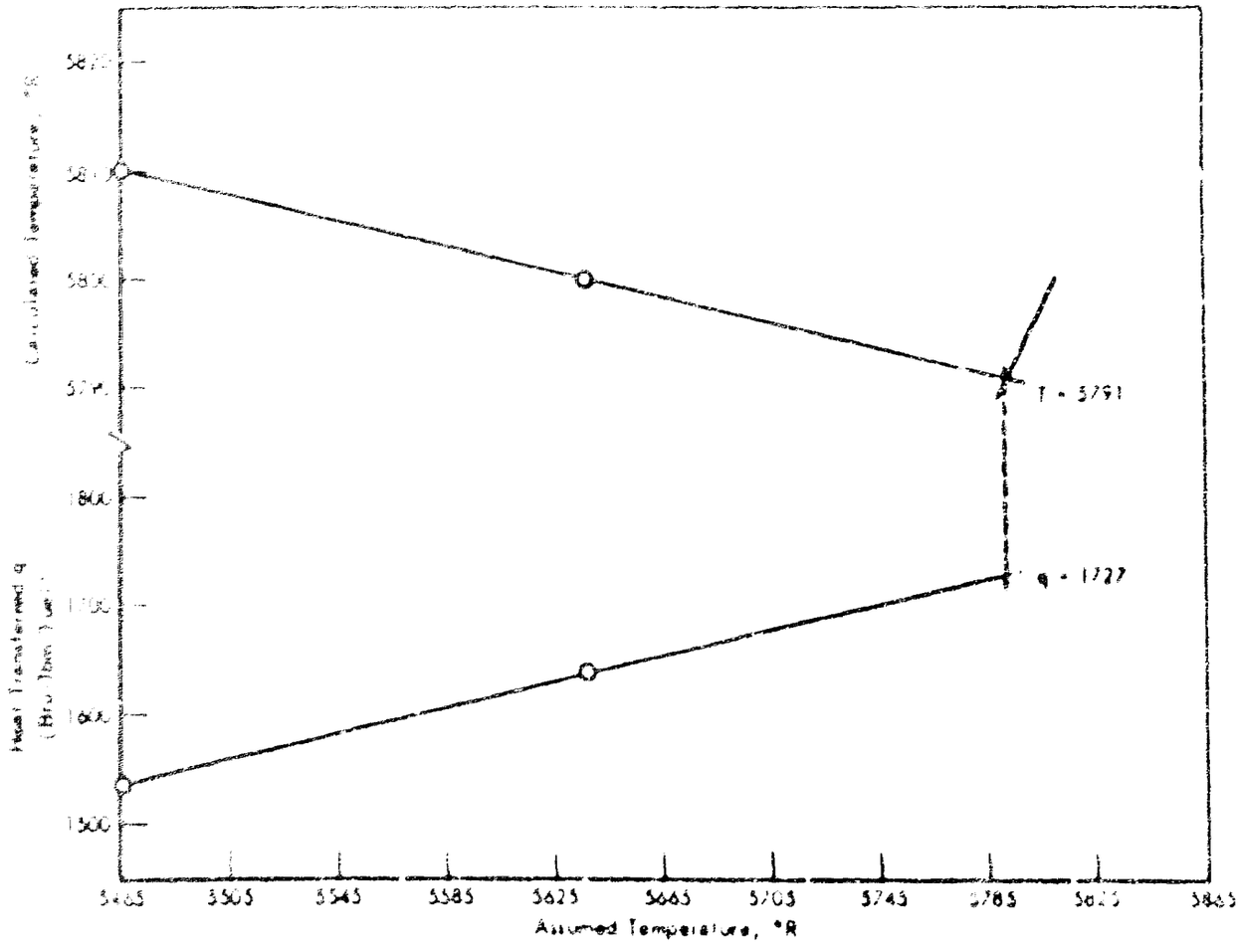


Figure 75. HEAT TRANSFER CONDITIONS

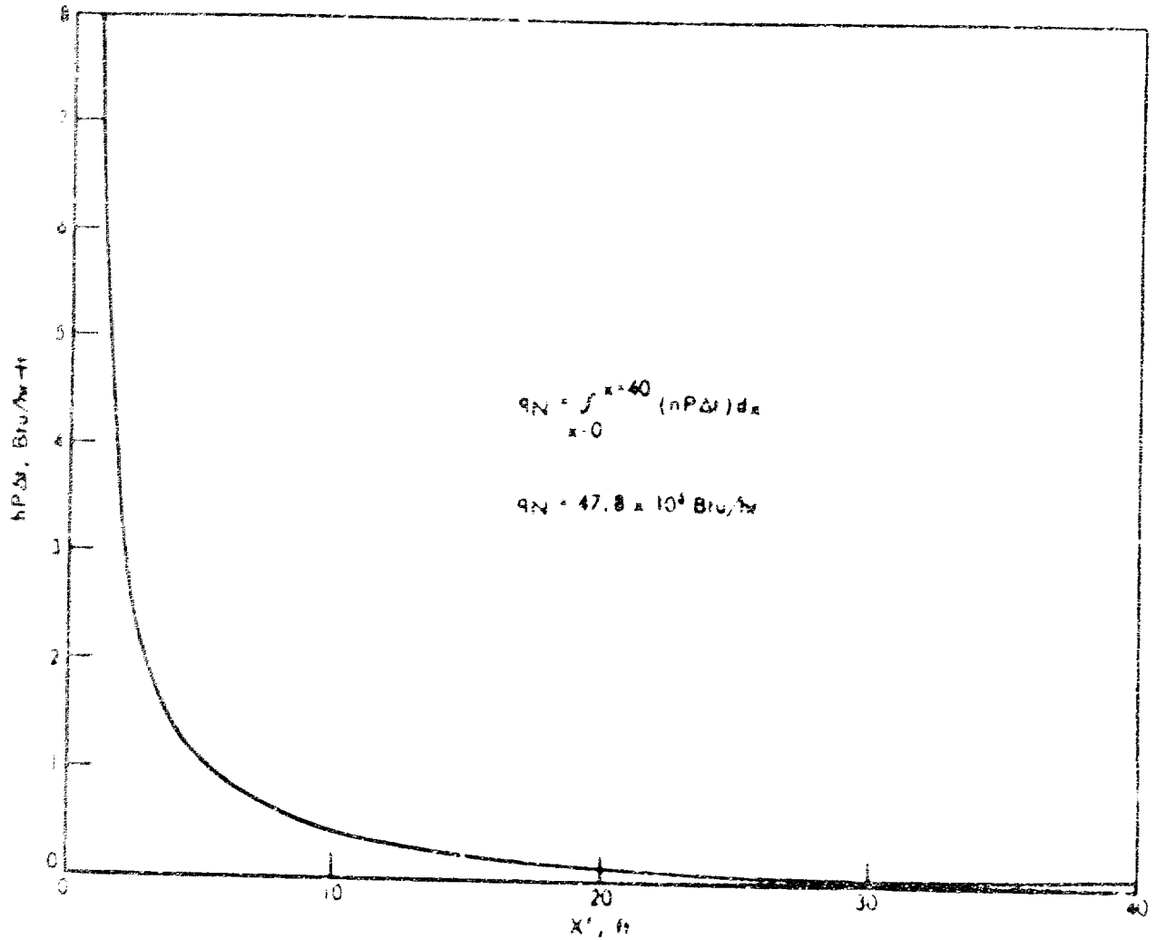


Figure 76. NOZZLE HEAT FLUX DISTRIBUTION

Table 112. DEHYDROGENATION OF MCH OVER AEROFORM PHF-4

Pressure: 1 atm Catalyst Volume: 7 ml
Block Temperature: 842 °F Reaction Time: 30 Minutes

Run Number 11213-	35	36-1	36-2	37
LHSV	5	15	30	50
Catalyst Bed Profile, °F	752 808-06 826-24 835-33	655-60 680-76 725-23 772-66	662-777 640-759 658-742 694-754	812-38[d] 820-36 813-35 808-35
Reactor Wall Temperature, °F	824-22	74-59	730-94	
ΔT max	0	5	135	27[d]
Product Analysis, %w				
3-heptene	1.8	0.2	0.0	0.0
U_1[a]	0.0	0.1	0.4	0.6
MCH	1.0	3.7	41.6	96.1
U_2[b]	0.0	0.0	0.0	1.0
Toluene	97.1	96.0	58.0	1.2
U_3[c]	0.1	0.0	0.0	1.1
MCH Conversion, %w	99.0	96.3	58.4	3.9

a) Unidentified; emerged after heptene.
b) Unidentified; emerged after MCH.
c) Unidentified; emerged after toluene.
d) Catalyst almost completely deactivated after 10 minutes.

Table 120. DEHYDROGENATION OF MCH OVER [illegible] 45

Pressure: 1 atm
Block Temperature: 842°F
Catalyst Volume: 7 ml
Reaction Time: 30 Minutes
Catalyst No.: 10280-45

Run Number: 10280-	93	94-1	94-2	100-1	100-2	101
LHSV	9	15	30	50	80[a]	100[a]
Catalyst Bed Profile, °F	790-88 824-22 855-53 840-38	671-67 714-07 754-48 795-92	630-22 635-23 651-44 650-73	619 610 617 633	626-30 608 608 617	635-42 608-10 608 614
Reactor Wall Temperature, °F	850	774-70	725-20	705	698	695-91
ΔT max	0	0	0	0	4[a]	7[a]
Product Analysis, %w Benzene MCH Toluene	9.9 1.1 89.0	0.9 0.5 98.6	0.1 19.3 80.6	0 0 41.2 58.7	0.0 54.6 45.4	0.1 60.5 39.5
MCH Conversion, %w	98.9	999.5	80.7	58.8	47.7	41.8

a) Back pressure was about 15 psig during this run.

Table L21. DEHYDROGENATION OF MCH OVER UOP-M6

Pressure: 1 atm
Block Temperature: 842°F Reaction Time: 30 Minutes

Run Number: 11018-	95-1	95-2	96
LHSV	5	15	30
Catalyst Bed Profile, °F	770-72 789-90 815-19 851-53	709-11 686-82 716-09 759-45	752-858 560-878 671-856 682-856
Reactor Wall Temperature, °F	815-30	775	768-858
ΔT max	4	2	168[d]
Product Analysis, %w			
Benzene	3.5	0.5	0
U_1[a]	0.0	0.0	0.3
MCH	1.3	6.1	84.7
U_2[b]	0.0	0.0	0.5
Toluene	95.0	93.5	12.5
U_3[c]	0.2	0.0	2.0
MCH Conversion, %w	98.7	95.9	15.3

a) Unidentified; emerged after benzene.
b) Unidentified; emerged after MCH.
c) Unidentified; emerged after toluene.
d) ΔT max = 162 after 17 minutes; catalyst completely deactivated at end of run.

Table 122. DEHYDROGENATION OF MCH OVER STANDARD CATALYST

Pressure: 1 atm
Block Temperature: 842°F
Catalyst Volume: 7 ml
Reaction Time: 30 Minutes
Catalyst No.: 9874-7

Run Number: MLY5-	73	72-1	72-2	00
LHSV	5	15	30	50
Catalyst Bed Profile, °F	779 775 850 857-35	714-16 745 765 788-86	725-76 725-59 734-54 748-59	815-37 797-853 783-833 777-850
Reactor Wall Temperature, °F	826	792	795-97	815-35
CF max	0	2	50	52[b]
Product Analysis, %w				
Benzene	1.7	0.4	0.2	0.1
MCH	1.	19.9	62.8	93.1
Toluene	97.2	79.7	37.0	5.6
U_1[a]	0.0	0.0	0.0	1.2
MCH Conversion, %w	98.9	80.1	37.2	6.9

a) Unidentified; emerged after toluene.
b) Catalyst almost completely deactivated at end of run.

Table 123. DEHYDROGENATION OF MCH OVER SHELL 108

Pressure: 1 atm
Block Temperature: 842°F
Catalyst Volume: 7 ml
Reaction Time: 30 Minutes
Catalyst Number: L0280-108

Run Number: 11018-	88-1	89-1	89-2	90-1	90-2	91
LHSV	5	15	30	50	80	100
Catalyst Bed Profile, °F	774-72 817-13 831 837-35	653 689 732-30 775	635-39 637 637-55 637-84	642-53 630-33 637-39 658	669-75 635-39 635-37 648	697-98 644-50 639-42 646-48
Reactor Wall Temperature, °F	826-24	761	727-25	716-18	716	725-29
ΔT max	0	0	4	11	6	7
Product Analysis, %w Benzene MCH Toluene	2.3 1.4 96.3	0.2 4.9 94.9	0.0 30.4 69.6	0.0 50.8 49.2	0.0 63.3 36.7	0.0 68.3 31.7
MCH Conversion, %w	98.6	95.1	69.6	49.3	36.9	31.9

Table 124. DEHYDROGENATION OF MCH OVER R8-150

Pressure: 1 atm Catalyst Volume: 7 ml
Block Temperature: 842°F Reaction Time: 30 Minutes

Run Number: 11618-	103-1	103-2	104-1	104-2	105
LHSV	5	15	30	50	80
Catalyst Bed Profile, °F	761-52 806-01 826-24 833	669-69 691-87 729-23 770-68	657-71 639-40 653-55 678-80	700-815 642-761 644-701 657-680	830-33 820-33 806-33 776-89
Reactor Wall Temperature, °F	822-20	763-61	727-29	725-88	824-35
ΔT max	0	0	14	115	--[d]
Product Analysis, %w					
Benzene	1.2	0.0	0.0	0.0	0.0
U_1[a]	0.0	0.1	0.0	0.2	0.2
MCH	1.4	2.2	27.5	56.1	96.6
U_2[b]	0.0	0.0	0.0	0.0	0.6
Toluene	97.4	97.7	72.5	43.7	1.6
U_3[c]	0.0	0.0	0.0	0.0	1.0
MCH Conversion, %w	98.6	97.8	72.5	43.9	3.4[d]

a) Unidentified; emerged after benzene.
b) Unidentified; emerged after MCH.
c) Unidentified; emerged after Toluene.
d) Catalyst about completely deactivated at end of run.

Table 125. DEHYDROGENATION OF MCH OVER UOP-R16E

Pressure: 1 atm
Block Temperature: 842°F
Catalyst Volume: 7 ml
Reaction Time: 30 minutes

Run No. 11325-	85-1	85-2	86-1	86-2	87-1	87-2
LHSV	5	15	30	50	80	100
Catalyst Bed Profile, °F	774-70 813-10 831-29 833	671 705-02 752-50 779-74	655-58 646-57 668-67 689-87	686-729 640-657 644-51 657-55	759-824 673-761 550-89 648-69[a]	824 784-822 705-761 678-720[a]
Reactor Wall Temp, °F	831	779-76	643-47	638-47	750-90	802-28
ΔT_{max}, °F	-4	-5	11	43	88[a]	31[a]
Product Analysis, %w						
Benzene	0.1	0.0	0.0	0.0	0.0	0.0
MCH	7.4	4.8	33.2	54.9	70.9	81.5
Toluene	92.4	95.2	66.8	45.1	29.0	18.0
Others[b]	0.1	0.0	0.0	0.0	0.1	0.5
MCH Conversion, %w	92.6	95.2	66.8	45.1	29.1	18.5

a) Cold spot moved down the catalyst bed.
b) Emerged after MCH and after toluene.

Table 126. DEHYDROGENATION OF MCH OVER 1% Pt on Al_2O_3

Pressure: 1 atm
Block Temperature: 842°F
Catalyst Volume: 7 ml
Reaction Time: 30 minutes
Catalyst No.: 10280-44

Run No. 11325-	81-1	81-2	82-1	82-2	83-1	83-2
LHSV	5	15	30	50	80	100
Catalyst Bed Profile, °F	776-72 817 833 837	686-82 732-27 765-61 795-92	669-76 689 711-09 741-39	685-743 687-707 696-707 718-22	776-815 729-90 716-66 720-54	819-24 806-24 786-819 772-812
Reactor Wall Temp, °F	831-28	781-76	750-52	747-61	770-810	817-831
ΔT_{max}, °F	-4	-5	+7	58	61[b]	40[b]
Product Analysis, %w						
Benzene	2.1	0.3	0.1	0.1	0.1	0.1
MCH	2.2	12.8	44.5	63.7	82.4	92.5
Toluene	95.7	86.9	55.2	35.8	16.7	4.9
Others[a]	0.0	0.0	0.2	0.4	0.8	2.5
MCH Conversion, %w	97.8	87.2	55.5	36.3	17.6	7.5
Selectivity for Toluene, %w	97.9	99.7	99.4	99.4	94.5	65.3

a) Emerged after MCH and after toluene.
b) Cold spot moved down the catalyst bed.

Table 127. DEHYDROGENATION OF MCH OVER 10860-114C CATALYST

Pressure: 1 atm
Block Temperature: 842°F
Catalyst Volume: 7 ml
Duration Time: 30 minutes

Run No. 11325-	74-1	74-2	75-1	75-2	76-1	76-2
LHSV	5	15	30	50	80	100
Catalyst Bed Profile, °F	759-61 815 833 837-35	640-35 689-82 750-43 792-84	619 632-30 660-57 691-89	621-26 621 635 658	635-37 619-21 626 644	644-50 621-23 626 637-35
Reactor Wall Temp, °F	831	770-66	730-28	718	711	709
ΔT_{max}, °F	+2	-8	-3	+5	+2	+6
Product Analysis, %w						
Benzene	5.4	0.5	0.1	0.0	0.0	0.0
MCH	2.2	1.7	26.8	47.2	59.6	65.0
Toluene	92.4	97.8	73.1	52.8	40.4	35.0
MCH Conversion, %w	97.8	98.3	73.2	52.8	40.4	35.0

Table LXS. DEHYDROGENATION OF MCH OVER 10660-1148 CATALYST

Pressure: 1 atm
Block Temperature, 842°F
Catalyst Volume: 7 ml
Reaction Time: 30 minutes

Run No. 11325-	69	T0-1	T0-2	T1	T2-1	T2-2
LHSV	5	15	30	50	80	100
Catalyst Bed Profile, °F	761-52 810-04 851-29 855-33	680-75 712-07 752-45 784-79	671-80 676 698-96 727-23	689-707 673-80 696- 707	727-68 687-709 687-714 696-702	781-806 723-63 700-25 702-16
Reactor Wall Temp, °F	828-26	779-76	752	743-47	747-63	758-95
ΔT_{max}, °F	-9	-7	+9	18	41	40[a]
Product Analysis, %w						
Benzene	0.8	0.2	0.1	0.1	0.1	0.1
MCH	0.8	10.8	44.3	62.2	73.3	81.3
Toluene	98.4	89.0	55.6	37.7	26.6	18.6
MCH Conversion, %w	99.2	89.2	55.7	37.8	26.7	18.7

a) Cold spot moved down the catalyst bed.

Table 129. DEHYDROGENATION OF MCH OVER 10660-113A AND HOUDRY 200 SR CATALYSTS

Pressure: 1 atm
Block Temperature: 840°F
Catalyst Volume: 7
Reaction Time: 30 minutes

Run No. 11325-	89-1	89-2	78-1	78-2	79
Catalyst	Houdry 200 SR		10660-113A		
LHSV	5	15	5	15	30
Catalyst Bed Profile, °F	758-56 801-799 826-24 833	705-833 700-831 741-830 770-828	763-58 804-797 824-19 831-28	725-68 741-50 762-58 784-779	824-37 797-833 774-826 770-817
Reactor Wall Temp, °F	826	783-838	824-21	788-97	820-837
ΔT_{max}, °F	-2	131	-7	43	b)
Product Analysis, %w					
Benzene	1.4	0.2	1.7	0.2	0.1
MCH	1.7	59.3	4.8	35.0	88.3
Toluene	96.9	34.1	93.5	64.8	10.8
Others[a]	0.0	6.2	0.0	0.0	0.8
MCH Conversion, %w	98.3	40.6	95.2	65.0	11.7
Selectivity for Toluene, %w	98.6	84.0	92.8	99.7	92.3

a) Emerged after MCH, after benzene, after toluene.
b) Catalyst bed temperature about that of reactor wall temperature.

Description of the Pulse Reactor

The pulse reactor was a 1/4-in. OD stainless steel tube (No. 304) 9-1/2 in. long and 0.028 in. wall thickness. Swagelok Tees were fastened at each end and one arm of the Tee served as an injection port. A rubber septum (GLC type) was held in place by the fitting nut and the feed was injected through this septum from a syringe. A five inch length of the reactor tube was surrounded by a secondary furnace liner and the whole was heated by an electric furnace. The secondary liner had seven radial drilled holes for thermocouples, and the holes were located as shown in Figure 79. A schematic diagram of the pulse reactor is shown in Figure 77.

All lines were 1/4-in. OD stainless steel tubing (No. 304). About 28 in. of line just prior to the reactor was wrapped with heating tape and constituted a gas preheater. About 8 in. of the preheater section was filled with quartz chips (10-20 mesh size).

In the pulse reactor system the carrier gas was metered through a rotameter (Figure 77) and passed through the preheater section and into the reactor. The exit gas passed into a manifold and then into the GLC. The purpose of the manifold was to maintain the exit gas pressure slightly greater than the gas pressure in the GLC. This was done by adjusting the pressure control valve and the vent valve. The manifold was wrapped with heating tape and was maintained at 302° to 356°F. The injection port temperature was about 450°F. The pressure control and the vent valves were needle valves (Hoke No. 1315) and the GLC valve was a lever operated valve (Hoke No. 490).

To carry out an experiment the reactor was brought to temperature and the carrier gas flow rate, reactor pressure and manifold pressure were adjusted by means of the appropriate flow control valves. Then with inert gas flowing to the GLC a pulse was injected through the lower injection port and subsequently analyzed. This gave an analysis of the starting material. A pulse was then injected in the top injection port, passed over the catalyst and analyzed.

In this system the space velocity was obtained from the inert gas flow rate. Figure 78 shows the pulse reactor system with the secondary furnace liner in place; Figure 80 shows the GLC analysis system.

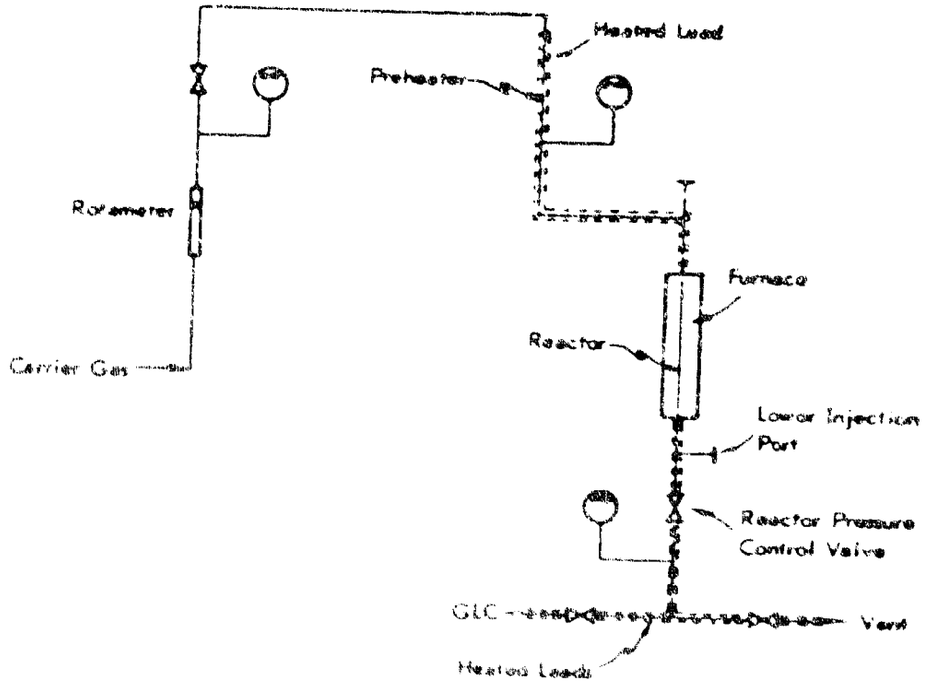


Figure 22. PULSE REACTOR SCHEMATIC

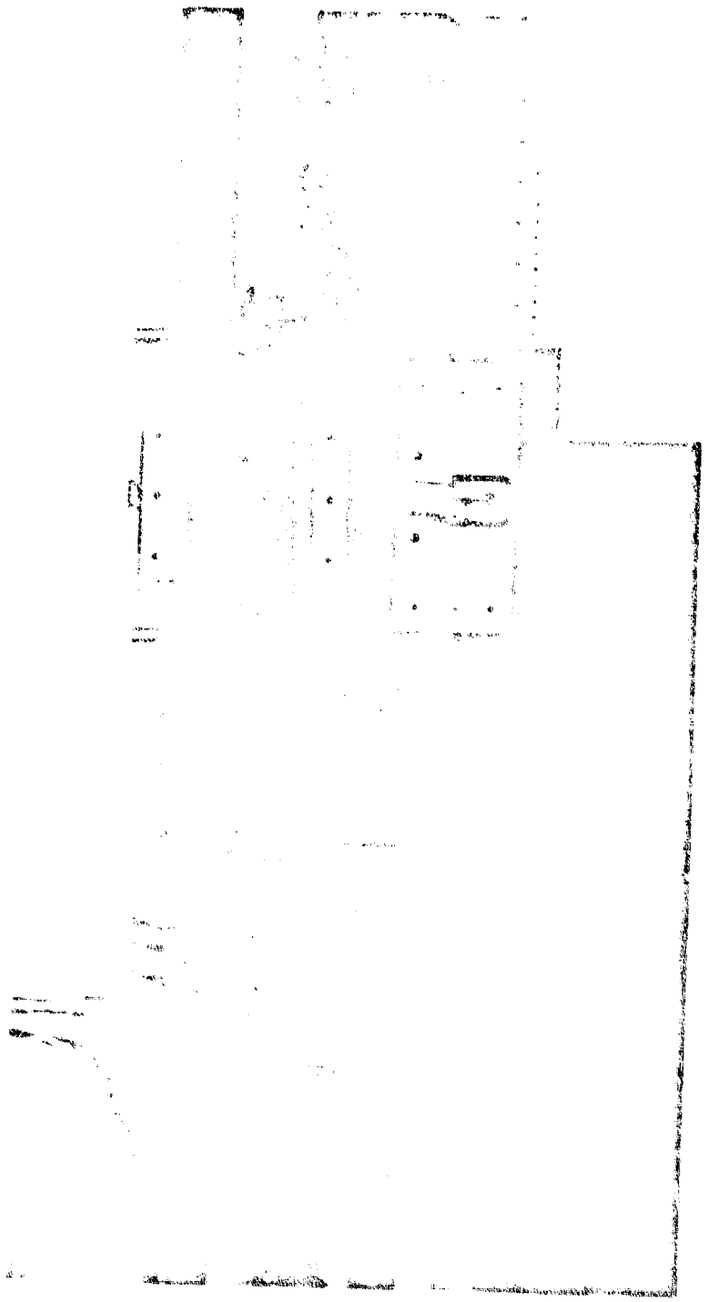


Figure 28. PULSE REACTOR SYSTEM

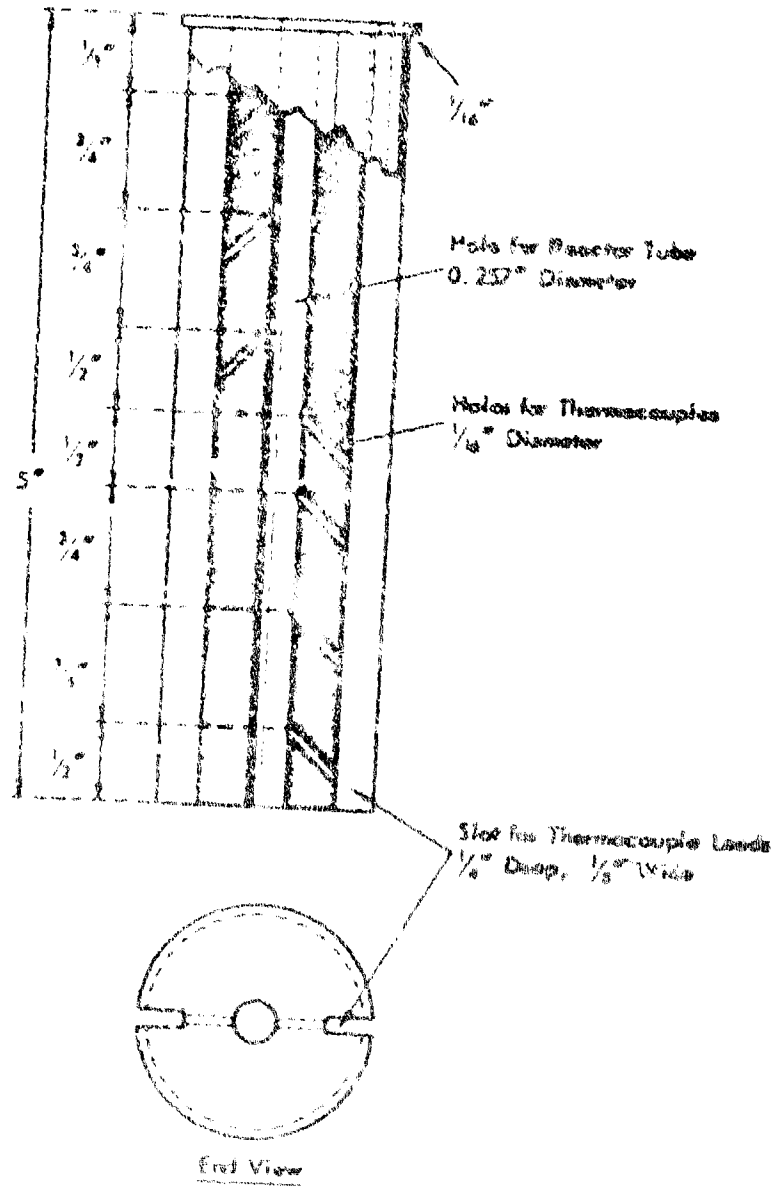


Figure 79. SECONDARY FURNACE LINER FOR PULSE REACTOR

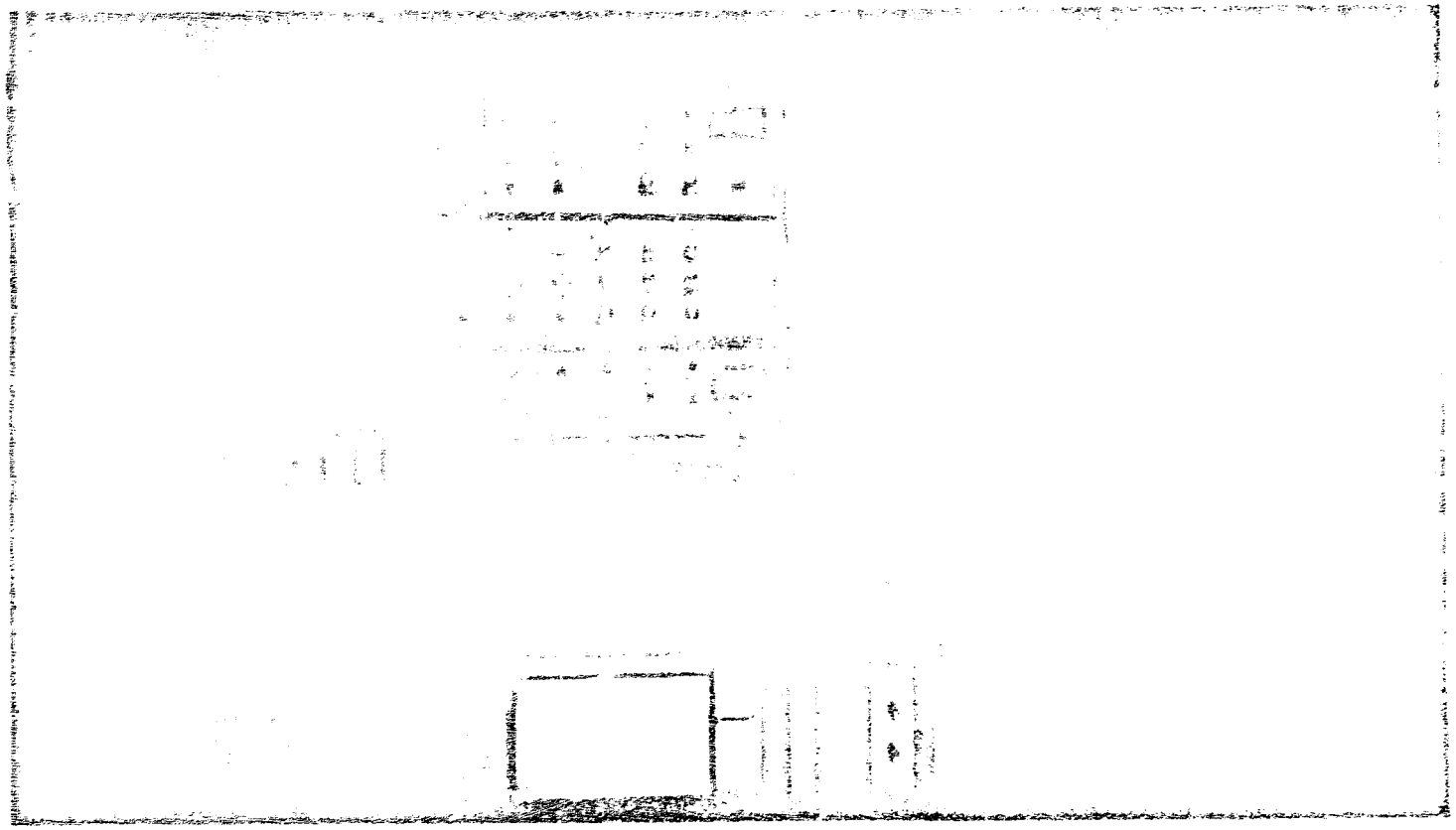


Figure 80. GIC ANALYSIS SYSTEM

Description of the 1/4-in. OD Flow Reactor

In order to test candidate fuels that are in short supply one section of our laboratory dual reactor system was modified in the following manner, so that 1/4-in. OD reactor tubes could be used.

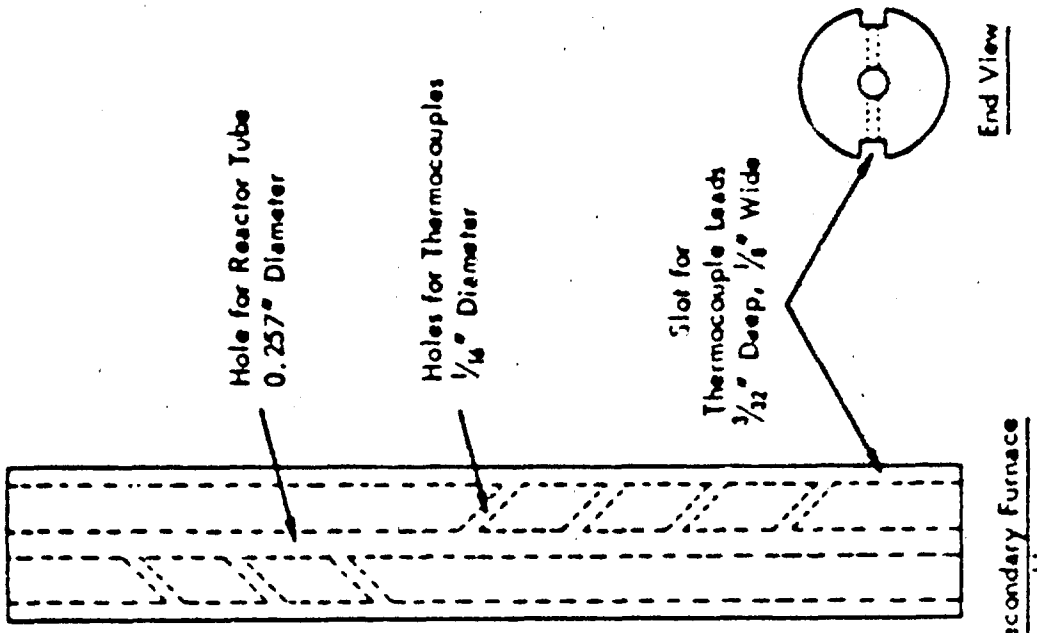
In our laboratory reactor system the furnace is 26 in. overall length and contains four heating elements of lengths 4", 8", 8", 4" located from top to bottom in that order. The outer shell of the furnace extends one inch beyond the top and bottom of the heating elements. The furnace consists of two hinged halves and opens lengthwise. Each half contains a heavy Meehanite liner with a groove down the center to hold the reactor tube. When closed the grooves form an opening 7/8 inch in diameter.

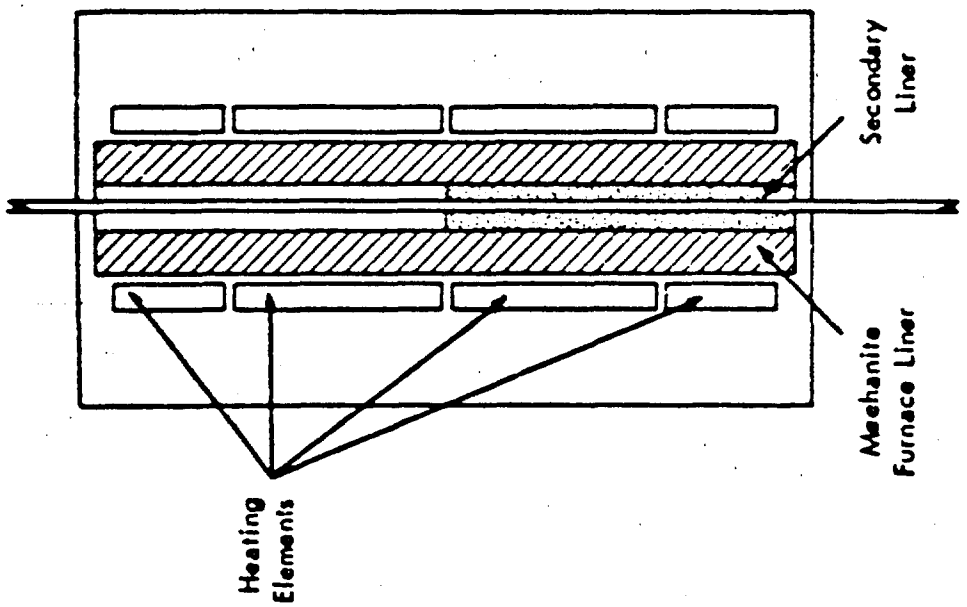
To modify the apparatus, a secondary furnace liner was fabricated from a 7/8-in. stainless steel rod (No. 416), 13 inches long. A 0.257-in. diameter hole was drilled down the center to accommodate a 1/4-in. OD reactor tube. Seven holes were drilled radially from the outside to the center hole in which thermocouples were cemented. The thermocouples were 1-1/2 inches apart and the top couple was 1-1/2 inches from the top of the liner. The thermocouples were situated so that they just touched the reactor wall. This secondary liner was placed in the Meehanite liners at the very bottom of the furnace and extended one inch below the bottom heating element. Figure 81 shows the construction of the secondary liner and its position in the furnace.

The reactor was a stainless steel tube (No. 304) 30 inches long, 1/4-inch OD with 0.035" wall thickness. Reaction was carried out in the lower part of the tube and the top part served as a feed preheater. The reactor was furnace-heated and a 13" long secondary furnace liner surrounded the reactor tube at the reaction zone. Figure 81 shows the secondary furnace liner and its position in the furnace.

The reactor wall temperature was measured at seven points along the tube. The points were 1-1/2 inches apart and the top point was one inch below the top of the secondary liner (Figure 81). The temperature of the reactor wall varied down the tube and Figure 82 shows the temperature variation for a furnace block temperature of 1202°F.

The maximum reaction rate will occur in the region of maximum temperature. Presumably the rate in that portion of the tube whose temperature was 18°F (10°C) or more below the maximum temperature, did not contribute appreciably to the overall rate. Thus the "effective" volume of the tube was that portion of the tube whose temperature was within 18°F of the maximum wall temperature, and whose volume was determined from a plot such as Figure 82. The "effective" reactor temperature was taken as 9°F below the maximum temperature.





Reactor Furnace with Secondary Furnace Liner In Position

Figure 81. SECONDARY FURNACE LINER FOR 1/4" OD REACTOR TUBE

63294

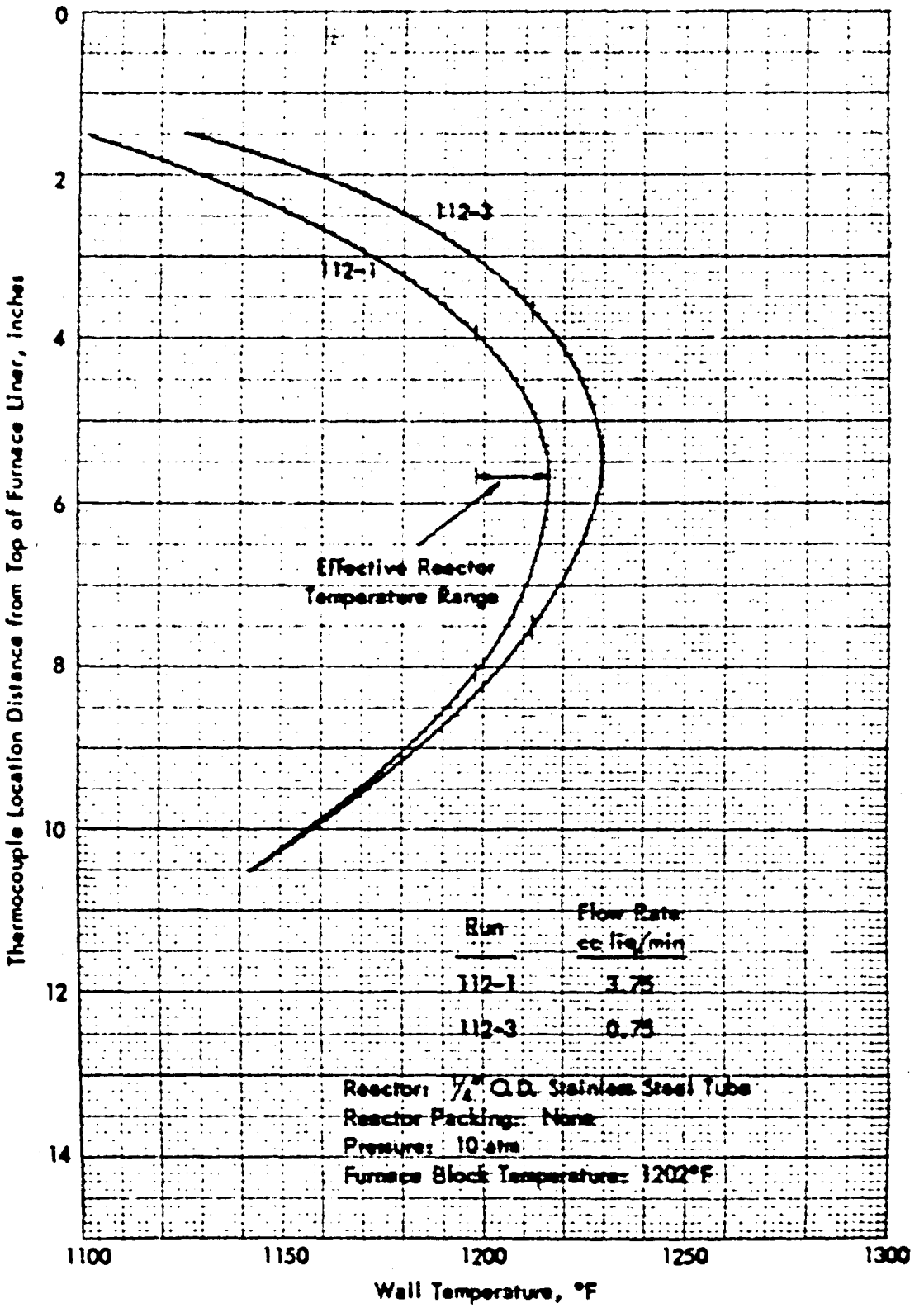


Figure 82. REACTOR TEMPERATURE PROFILE

Micro Catalyst Test Reactor Data

The micro catalyst test reactor (MICTR) and the operational techniques used for screening candidate catalysts have been described in the Appendix of the last Annual Report.[16] No further changes have been made. Catalysts are tested with MCH at LHSV 100 and 662, 752 and 842°F, at 10 atm pressure without added hydrogen. Figures 87 through 89, of reference 18 show the apparatus in detail, except for the changes noted in reference 16. It has been found that more consistent results are obtained if a fresh loading of the reference catalyst 9874-139 is made each week as a base point for calibration, rather than using the same reference catalyst tube over and over again, since the activity gradually declines. Also prepared catalysts have been rescreened to 10-20 mesh to remove fines after impregnation and drying of the supports, and this gives more reproducible results.

Table 130. MCH DEHYDROGENATION WITH VARIOUS CATALYSTS IN MICRO REAC 677-813

Period: June-August 1968
Condition: 10 atm pressure; catalysts reduced in H_2 for 20 minutes at 796°F; GLC samples normally taken at 3-, 8-, and 13-minute operation at each block temperature.
Catalyst Volume: 0.9 ml catalyst diluted with 1.1 ml quartz chips; LHSV 100 (catalyst and quartz particles 10-20 mesh unless otherwise noted).

Run No.	Catalyst No.	Composition	Weight	MCH Conversion, %		
677		1% Pt/SiO2-Al2O3 (ref)	1.047	68, 65, 58	68, 68, 68	70, 70, 70
678		Pt-Re, 1% Pt, Re/1% Pt = 0.5, on SiO2-Al2O3 type 6 support	1.074	5, 5	5, 5	5, 5
679		Pt-Re, 1% Pt, Re/1% Pt = 1.0, on SiO2-Al2O3 type 6 support	0.958	5, 5	5, 5	4[5]
680		Pt-Re, 1% Pt, Re/1% Pt = 2.0, on SiO2-Al2O3	1.018	4[5]	4[5]	4[5]
681		Pt-Re, 1% Pt, Re/1% Pt = 4.0, on SiO2-Al2O3	1.088	3	3	3
682		1% Pt/SiO2-Al2O3 type 6 support	1.148	3	3	3
683		1% Pt/SiO2-Al2O3 type 1 support	1.098	74, 68, 68	74, 72, 70[5]	78, 77, 76[5]
					68, 70, 71	66, 70, 71
684		1% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.948	68, 67, 68	72, 74, 74	77, 77, 78
685		1% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.948	67, 67, 68	68, 68, 67	78, 75, 79
686		1% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.948	68, 67, 68	72, 74, 74	78, 77, 77
687		1% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.941	68, 67, 67	72, 68, 69	74, 75, 75
688		1% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.948	65, 65, 65	72, 68, 68	76, 77, 78
689		1% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.939	65, 68, 68	74, 74, 68	75, 75, 75
690		Pt-Re/SiO2-Al2O3 type 1 support	0.974	67, 65, 65	68, 67, 68	71, 70, 70
691		1% Pt-Re/SiO2-Al2O3 type 1 support	0.9733	67, 68, 68	68, 68, 68	70[5], 70, 70[5]
				70, 70, 70	70, 70, 70	68, 70, 70
692		1% Pt-Re/SiO2-Al2O3 type 1 support	0.969	68, 68, 68	68, 68, 68	68[5], 68, 68[5]
				68, 68, 68	68, 68, 68	68, 68, 68
693		Pt-Re, 1% Pt, Re/1% Pt = 0.5, on SiO2-Al2O3	0.9733	65, 65, 65	65, 65, 65	77, 80, 80
694		Pt-Re, 1% Pt, Re/1% Pt = 1.0, on SiO2-Al2O3	0.9773	70, 70, 68	80, 78, 78	75, 80, 80
695		Pt-Re, 1% Pt, Re/1% Pt = 2.0, on SiO2-Al2O3	0.9773	68, 67, 67	68, 68, 68	75, 80, 75
696		Pt-Re, 1% Pt, Re/1% Pt = 4.0, on SiO2-Al2O3	0.9773	68, 68, 68	68, 68, 68	75, 80, 75
697		1% Pt/SiO2-Al2O3 type 1 support	0.984	70, 70, 70	68, 68, 68	78, 80, 77
698		1% Pt/SiO2-Al2O3 type 1 support	0.968	68, 68, 7	78, 78, 78	78, 78, 78[5]
						80, 80, 80
699		Pt-Re/SiO2-Al2O3 type 1 support	0.984	7, 7, 11	78, 78, 72	80, 78, 78
700		0.5% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.948	68, 68, 68	78, 68, 68	78, 75, 75
701		1.5% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.948	68, 68, 68	78, 78, 78	80, 78, 80
702		3.5% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.888	68, 68, 68	77, 78, 78	80, 80, 80
703		Pt-Re/SiO2-Al2O3 type 1 support	0.888	68, 70, 70[5,6]	80, 80[5], 80[5,6]	80, 80[5], 80[5]
				77, 77, 77	77, 77, 78	78, 78, 78
704		Pt-Re, 1% Pt, Re/1% Pt = 0.5, on SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	-	68, 68, 68	68, 68, 68[5]	70, 70, 70[5]
					78, 78, 77	78, 78, 80
705		1% Pt/SiO2-Al2O3 type 6 support (ref)	0.939	78, 78, 78	77, 78, 78	75, 78, 78
706		0.5% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 6 support	1.048	78, 78, 78	78, 78, 78	68, 78, 78
707		1% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 6 support	1.098	78, 78, 78	78, 78, 78	72, 77, 75
708		3% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.948	78, 78, 78	78, 78, 78	77, 78, 68
709		5% Pt/SiO2-Al2O3 type 1 support; /SiO2-Al2O3 type 2 support; /SiO2-Al2O3 type 6 support	0.952	78, 77, 78	78, 78, 78	78, 78, 78, 77
710		1% Pt/support type 1, 7 km reference[4]	0.888	78, 78, 78	78, 77, 78	77, 78, 78
711		1% Pt/support type 1, 6 km ref.[4]	0.888	78, 78, 77	68, 68, 68	71, 67, 67
712		1% Pt/support type 1, 6 km ref.[4]	0.888	78, 78, 78	77, 78, 77	77, 78, 78

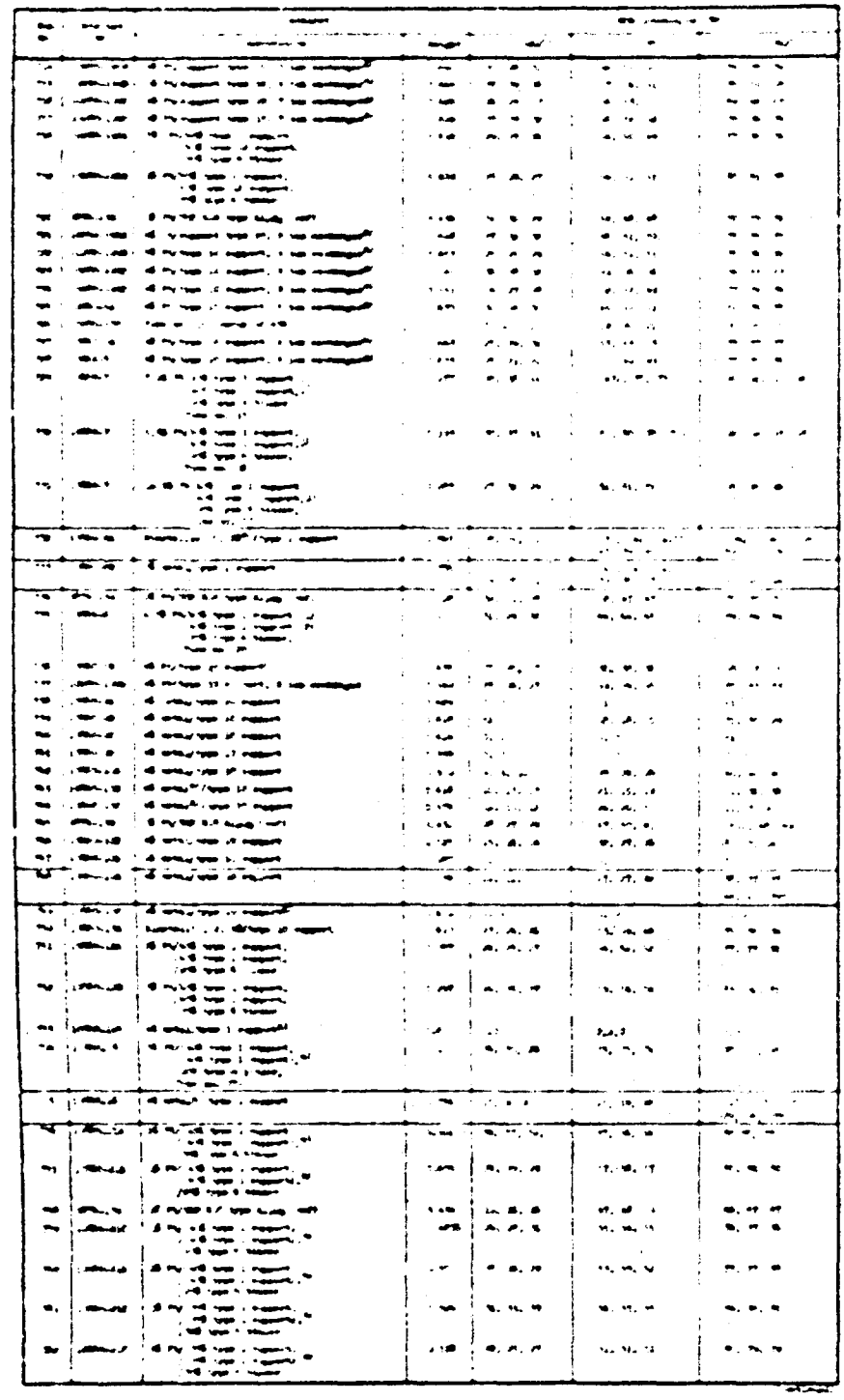


Table 3.9 (Cont'd-2). [illegible]

[illegible]					
[illegible]					

[illegible]

Table XII. [illegible]

Period: September-November 1966
Conditions: 10 atm pressure; catalysts reduced in H_2 for 20 minutes at 750°F; [illegible] samples normally taken at 5, 8, and 15 minute operation at each block temperature.
Catalyst Volume: 0.9 ml catalyst diluted with 1.1 ml quartz chips; LHSV 100 (catalyst and quartz 10-20 mesh unless otherwise noted

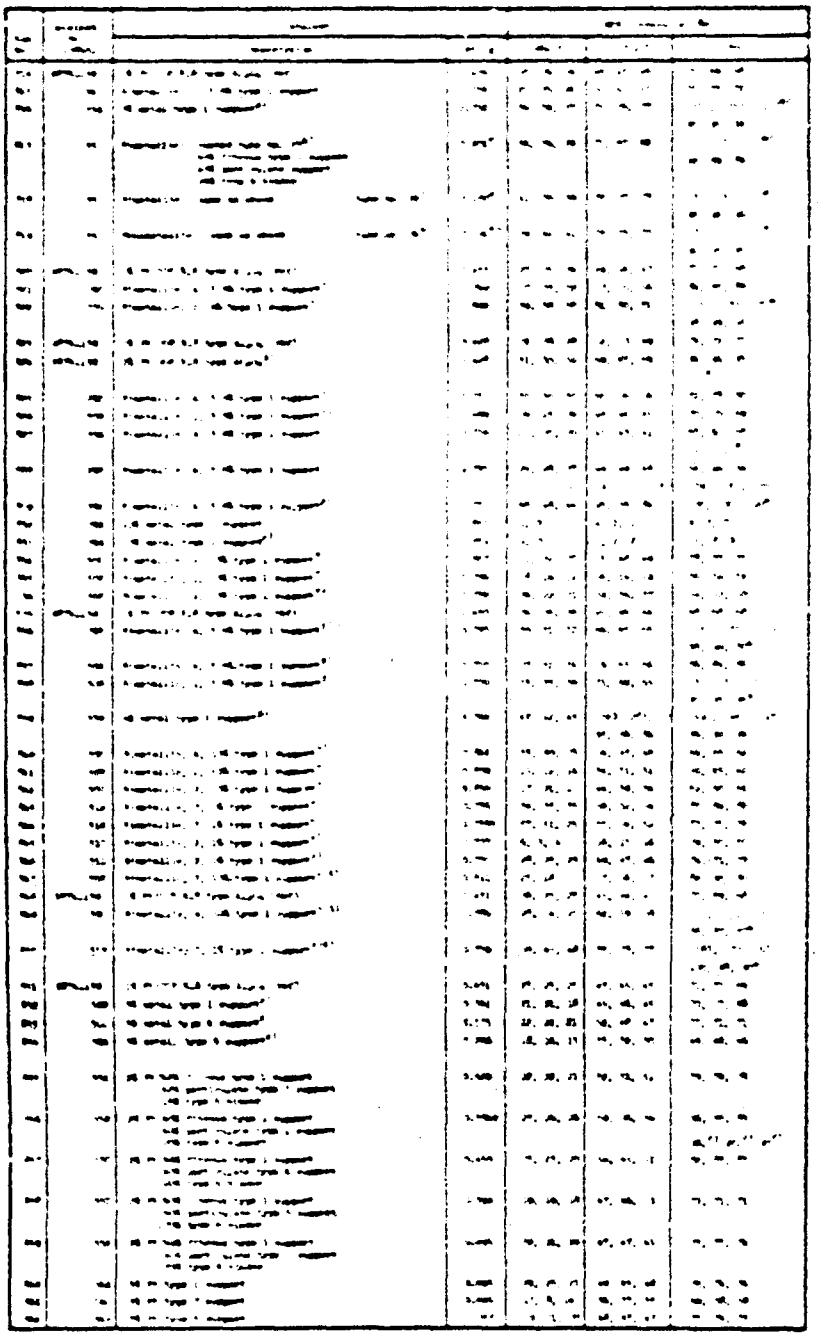


Table XII. MCH DEHYDROGENATION WITH VARIOUS CATALYSTS IN FLOW REACTOR

Period: December, 1968-February, 1969
Conditions: 10 atm pressure; catalysts reduced in hydrogen at 796°F. GLC samples taken normally at 3-, 8- and 13-minute operation at each temperature.
Volume: 0.9 ml catalyst diluted with 1.1 ml quartz chips (10-20 mesh). LHSV 100 with MCH

Run No.	Catalyst No.	Catalyst Description	Vol., cc	MCH Conversion, %		
				446°F	796°F	896°F
[illegible]	[illegible]	1% Pt-[illegible] B.A type Al$_2$O$_3$ (ref.)	0.611	25, 25, 26	56, 58, 57	69, 69, 70
[illegible]	[illegible]	1% metal type 1 support[1]	0.658	0, 0	0, 0	0, 0
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.778	21, 23, 23	57, [illegible], 57	68, 69, 69
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.776	16, 14, 14	38, 36, 36	57, 51, 50
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	2, 2	[illegible], [illegible]	[illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support	0.[illegible]	27, 25, 18	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	3, 3, 3	17, 20, 20	45, 46, 51
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.814	0, 0	0, 0	0, 0
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	21, 20, 23	56, 57, 56	72, 72, 72
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	18, 18, 17	46, 46, 45	71, 70, 70
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	2, 2, 2	2, 2, 1	2, 1, 1
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	9, 9, 9	14, 15, 16	17, 16, 16
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	23, 25, 24	45, 46, 47	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support	0.[illegible]	[illegible]	[illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support	0.565	21, 20, 20	[illegible], 54, 55	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support	0.[illegible]	[illegible]	[illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% Pt-[illegible] B.A type Al$_2$O$_3$ (ref.)	0.608	23, 23, 23	50, 48, 48	72, 72, 73
[illegible]	[illegible]	1% metal type 1 support	0.789	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support	0.810	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support[1]	0.[illegible]	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support[1]	0.[illegible]	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support[1]	0.[illegible]	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support[1]	0.811	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Tube no. [illegible]: 1% metal on 60% type 1 support (1), 40% type 1 support (2), [illegible]	0.[illegible]	18, 17, 19	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Tube no. [illegible]: 1% metal on above support	0.[illegible]	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal on 60% type 1 support (1), 40% type 1 support (2); binders, 17% type 6, 1% type [illegible]	0.[illegible]	26, 25, 24	52, 52, 53	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal on above support	0.[illegible]	28, 25, 25	55, 51, 48	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% Pt-[illegible] B.A type Al$_2$O$_3$ (ref.)	0.[illegible]	28, 25, 23	55, 54, 53	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal on same type support used for catalyst 6[illegible] but less type 22 binder	0.[illegible]	27, 25, 26	49, 50, 52	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal on same type support used for catalyst 6[illegible] but less type 22 binder	0.[illegible]	20, 21, 21	34, 30, 30	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	2, 2, 2	5, 4, 3	10, 9, 8
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	6, 6, 6	17, 17, 16	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	3, 4, 3	5, 5, 4	15, [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	[illegible]	[illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support	0.[illegible]	[illegible]	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	19, 18, 16	[illegible], [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	24, 22, 22	50, [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	20, 21, 22	47, [illegible], [illegible]	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support[1]	0.[illegible]	2, 1, 1	2, 0, 0	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% metal type 1 support[1]	0.[illegible]	0, 0	0, 0	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1% type 1 support[1]	0.[illegible]	11, 8, 7	17, 15, 13	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1.6% metal type 1 support[1]	0.[illegible]	1, 2, 1	3, 2, 2	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1% Pt-[illegible] B.A type Al$_2$O$_3$ (ref.)	0.[illegible]	25, 24, 25	47, 47, 46	[illegible], [illegible], [illegible]
[illegible]	[illegible]	1.6% metal type 1 support[1]	0.[illegible]	0, 0	0, 0	[illegible], [illegible], [illegible]
[illegible]	[illegible]	Bimetallic 2, 1.6% type 1 support[1]	0.[illegible]	17, 17, 16	36, 35, 35	[illegible], [illegible], [illegible]

a) LHSV 40.
b) Impregnated as 2,2'-dipyridyl chelate.
c) Impregnated as ethylenediamine chelate.
d) Quartz filled.
e) Catalyst muffled 1 hr at 1[illegible]°F in air, before reduction.
f) Catalyst muffled 1 hr at 1[illegible]°F in air, before reduction.
g) Catalyst reduced at 1[illegible]°F.
h) Catalyst muffled 1 hr at 1[illegible]°F in air, then reduced at 1[illegible]°F.
i) Catalyst reduced at [illegible]°F.
j) Calculated from the toluene-benzene-residual methylcyclohexane ratio; 6 benzene in parentheses. Considerable cracking to light gases, not determined.

Table III. MCH DEHYDROGENATION WITH VARIOUS CATALYSTS IN MICRO FLOW [illegible]

Period: March-August, 1969
Conditions: 10 atm pressure; catalysts reduced in hydrogen at 736°F, GLC samples taken normally at 3-, 8- and 13-minute operation at each temperature
Volume: 0.9 ml catalyst diluted with 1.1 ml quartz chips (10-20 mesh). LHSV 100 with MCH

Run No.	Catalyst Number	Catalyst Description	Wt. g	% MCH Conversion, Hr 1	Hr 2	Hr 3
905	[illegible]	15 Pt/5 [illegible] type 1 support /5 type 1 support as No. 21 /[illegible]	1.277	28[illegible], 29, 26	30, 28, 27	30, 28, 28
907	10880-64B	25 Pt/5 [illegible] type 1 support /5 type 1 support as No. 21 /[illegible]	1.270	29, 29, 29	[illegible], 31, 29	28, 27, 27
908	10880-71	1.65 wt% type 1 support	1.184	0, 0	0, 0	0, 0, 0
909	10880-71A	3.65 wt% type 1 support[b]	1.278	0, 0	<1	0, 0, 0
910	10880-71B	Platinelle, 2, 3.6% type 1 support[a]	0.776	29, 28, 26	28, 25, 24	28, 26, 26
911	10880-71C	Platinelle, 2, 3.6% type 1 support[a]	0.805	28, 26, 25	25, 24, 23	25, 27, 25
912	10880-71D	Platinelle, 2, 3.6% type 1 support[a]	0.779	24, 24, 23	25, 25, 26	26, 26, 26
913	10880-71E	Platinelle, 2, 3.6% type 1 support[a]	0.778	25, 26, 25	30, 27, 28	28, 29, 29
914	10880-71F	Platinelle, 2, 3.6% type 1 support[a]	0.784	<1	0, 0, 0	0, 0, 0
915	10880-72A	Platinelle, 2, 3.6% type 1 support[a]	0.774	28, 26, 26	33, 32, 32	27, 27, 28
916	10880-72B	Platinelle, 2, 3.6% type 1 support[a]	0.775	16, 17, 17	27, 27, 26	27, 27, 27
917	9978-139	15 Pt/BDP 8-8 type Al_2O_3 (ref.)	0.633	27, 25, 26	27, 28, 28	25, 25, 25
918	10880-72C	Platinelle, 2, 3.6% type 1 support[b]	0.778	11, 11, 12	26, 26, 26	26, 26, 27
919	10880-72D	Platinelle, 2, 3.6% type 1 support[b]	0.778	23, 26, 25	32, 30, 28	25, 25, 25
920	10880-72E	Platinelle, 2, 3.6% type 1 support[b]	0.778	2, <1	0, 0, 0	0, 0, 0
921	10880-71C	Platinelle, 2, 3.6% type 1 support[a]	0.813	33, 31, 32	30, 29, 25	[illegible], 23, [illegible][a] 28, 26, 28
922	10880-6A	Platinelle, 2, 3.6% type 1 support[a]	0.784	28, 26, 26	28, 26, 25	26, 25, 25
923	10880-72G	Platinelle, 2, 3.6% type 1 support[a]	0.779	22, 23, 24	26, 25, 24	26, 26, 26
924	10880-72H	Platinelle, 2, 3.6% type 1 support[a]	0.781	26, 25, 26	29, 27, 27	28, 27, 27
925	10880-72I	Platinelle, 2, 3.6% type 1 support[a]	0.768	19, 21, 21	23, 23, 23	23, 24, 23
926	10880-72J	Platinelle, 2, 3.6% type 1 support[a]	0.782	22, 21, 23	26, 27, 26	27, 25, 24
927	10880-72K	Platinelle, 2, 3.6% type 1 support[a][c]	0.781	[illegible], 27, 28	29, 27, 29	[illegible], [illegible], [illegible][a] 27, 27, 28
928	10880-6B	25 Pt/type 5 support	0.771	19, 21, 21	27, 27, 26	25, 25, 26
929	10880-6C	45 Pt/type 5 support	0.779	15, 16, 15	23, 25, 25	21, 26, 26
930	9978-139	15 Pt/BDP 8-8 type Al_2O_3	0.633	30, 28, 28	28, 27, 26	29, 28, 29
931	10880-72E	Platinelle, 2, 3.6% type 1 support	0.775	7, 9, 9	6, 6, 6	12, 11, 12
932	10880-6A	Platinelle, 2, 3.6% type 1 support[a]	0.772	28, 28, 28	25, 25, 25	28, 25, 28
933	10880-6AA	25 Pt/type 1 support[a]	0.736	29, 29, 29	25, 25, 25	26, 25, 25
934	10880-6BC	25 Pt/type 5 support	0.743	25, 28, 29	25, 26, 28	27, 27, 25
935	10880-67A	Platinelle, 2, 3.6% type 1 support[a][d]	0.739	29, 27, 26	27, 25, 25	25, 25, 25
936	10880-67B	Platinelle, 2, 3.6% type 1 support[a]	0.750	[illegible], 27, 26	28, 32, 32	30, 31, 30
937	10880-67C	Platinelle, 2, 3.6% type 1 support[a]	0.718	25, 30, 26	28, 34, 33	29, 28, 28
938	10880-67D	Platinelle, 2, 3.6% type 1 support[a]	0.726	19, 20, 19	31, 26, 26	26, 26, 26
939	10880-67E	Platinelle, 2, 3.6% type 1 support[a]	0.648	27, 26, 26	27, 28, 26	27, 27, 25
940	10880-68A	25 Pt/bCA type 1 support /bCA type 5 support /bCA type 6 binder	2.380	30, 28, 29	30, 29, 26	28, 27, 28
941	10880-68B	25 Pt/bCA type 1 support /bCA type 5 support /bCA type 6 binder	2.384	28, 27, 26	30, 30, 29	29, 28, 28
942	10880-68C	25 Pt/STA type 1 support /STA type 5 support /STA type 6 binder	0.417	20, 21, 20	24, 23, 29	25, 21, 20
943	10880-68D	25 Pt/STA type 1 support /STA type 5 support /STA type 6 binder	0.436	22, 23, 23	31, 28, 27	29, 27, 29
944	9978-139	15 Pt/BDP 8-8 type Al_2O_3	0.632	[illegible], 1, 25	26, 25, 26	24, 25, 24

(Continued)

Table 133 (Cont'd-1). MCH DEHYDROGENATION WITH VARIOUS CATALYSTS IN MICRO-REACTOR, RUNS 906-1000

Run No.	Catalyst No.	Description	Wt. g	% MCH Conversion to Toluene	% MCH Conversion to Methylcyclohexene	% MCH Conversion to Methylcyclohexadiene
906	[illegible]	[illegible]	0.750	21, 26, 21	51, 48, 49	27, 25, 30
907	[illegible]	[illegible]	0.750	26, 26, 28	55, 52, 50	19, 22, 22
908	[illegible]	[illegible]	0.750	13, 20, 16	68, 68, 68	19, 12, 16
909	[illegible]	[illegible]	0.750	17, 21, 19	68, 68, 68	15, 11, 13
910	[illegible]	[illegible]	0.750	<2	3, 2, 2	2, 2, 2
911	[illegible]	25 Pt/SiO2 0.6 type 1 support .75 type 1 support .75 type 6 blank	0.750	22, 22, 20	57, 56, 56	20, 20, 24
912	[illegible]	25 Pt/SiO2 type 1 support	0.750	22, 23, 25	46, 45, 47	32, 32, 28
913	[illegible]	.75 Pt/SiO2 type 1 support	0.750	2, 2	3, 3	2, 2
914	[illegible]	Pt/SiO2 type 1 support	0.750	25, 26, 28	59, 59, 53	28, 25, 24
915	[illegible]	Pt/SiO2 type 1 support	0.750	21, 24, 24	51, 49, 47	27, 27, 27
916	[illegible]	Pt/SiO2 type 1 support	0.750	22, 23, 23	56, 55, 53	22, 22, 23
917	[illegible]	Pt/SiO2 type 1 support	0.750	20, 20, 20	57, 55, 56	23, 25, 24
918	[illegible]	45 Pt/SiO2 type 1 support	0.750	1, 1, 1	3, 3, 3	4, 13, 16
919	[illegible]	.5 Pt/SiO2 0.6 type 1 support (ref.)	0.675	21, 22, 22	48, 48, 47	23, 23, 22
920	[illegible]	Pt/SiO2 type 1 support	0.750	20, 20, 22	46, 46, 46	27, 29, 22
921	[illegible]	Pt/SiO2 type 1 support	0.750	18, 20, 22	40, 47, 46	35, 33, 32
922	[illegible]	25 Pt/SiO2 type 1 support .75 type 1 support .75 type 6 blank	0.750	22, 24, 22	58, 51, 51	18, 25, 27
923	[illegible]	25 Pt/SiO2 type 1 support .75 type 1 support .75 type 6 blank	0.750	15, 20, 22	60, 58, 60	25, 22, 18
924	[illegible]	25 Pt/SiO2 type 1 support .75 type 1 support .75 type 6 blank	0.750	25, 25, 24	55, 55, 56	20, 20, 20
925	[illegible]	25 Pt/SiO2 type 1 support .75 type 1 support .75 type 6 blank	0.750	20, 20, 20	57, 54, 56	23, 26, 24
926	[illegible]	25 Pt/SiO2 type 1 support .75 type 1 support .75 type 6 blank	0.750	20, 20, 20	48, 57, 56	32, 23, 24
927	[illegible]	25 Pt/SiO2 type 1 support .75 type 1 support .75 type 6 blank	0.750	20, 20, 20	53, 54, 53	27, 26, (36)
928	[illegible]	25 Pt/SiO2 type 1 support .75 type 1 support .75 type 6 blank	0.750	20, 22, 20	57, 56, 56	23, 22, 24
929	[illegible]	5 wt% type 1 support	0.750	0, 0	0, 0	0, 0
930	[illegible]	Pt/Al2O3 type 1 support	0.750	17, 20, 22	67, 65, 66	16, 15, 12
931	[illegible]	Pt/Al2O3 type 1 support	0.750	20, 20, 20	58, 58, 59	22, 22, 21
932	[illegible]	Pt/Al2O3 type 1 support	0.750	0, 0	<2	2, 2, 2
933	[illegible]	25 Pt/SiO2 0.6 type 1 support (ref.)	0.675	22, 27, 27	46, 47, 47	32, 26, 26
934	[illegible]	Pt/Al2O3 type 1 support	0.750	25, 25, 25	51, 49, 50	24, 26, 25
935	[illegible]	Pt/Al2O3 type 1 support	0.750	16, 17, 22	35, 35, 35	50, 48, 43
936	[illegible]	Pt/Al2O3 type 1 support	0.750	13, 17, 19	33, 36, 43	54, 47, 38
937	[illegible]	Pt/Al2O3 type 1 support	0.750	20, 22, 22	43, 38, 39	36, 40, 40
938	[illegible]	Pt/Al2O3 type 1 support	0.750	0, 0	0, 0	<2
939	[illegible]	Pt/Al2O3 type 1 support	0.750	20, 25, 20	47, 50, 50	32, 25, 30
940	[illegible]	Pt/Al2O3 type 1 support	0.750	21, 20, 20	61, 56, 56	18, 24, 24
941	[illegible]	Pt/Al2O3 type 1 support	0.750	25, 20, 25	48, 47, 47	28, 33, 28
942	[illegible]	Pt/Al2O3 type 1 support	0.750	22, 20, 20	50, 54, 50	32, 26, 30
943	[illegible]	Pt/Al2O3 type 1 support	0.750	1, 1, 1	1, 1, 1	3, 2, 1
944	[illegible]	Pt/Al2O3 type 1 support	0.750	20, 22, 22	53, 50, 50	28, 28, 28
945	[illegible]	Pt/Al2O3 type 1 support	0.750	25, 25, 25	38, 38, 38	36, 35, 32
946	[illegible]	Pt/Al2O3 type 1 support	0.750	6, 9, 9	46, 46, 46	48, 46, 46
947	[illegible]	Pt/Al2O3 type 1 support	0.750	20, 23, 23	51, 51, 48	29, 26, 29
948	[illegible]	Pt/Al2O3 type 1 support	0.750	0, 0	0, 0	3, 2, 1
949	[illegible]	25 Pt/SiO2 0.6 type 1 support (ref.)	0.675	20, 20, 20	47, 47, 47	33, 33, 33
950	[illegible]	Pt/Al2O3 type 1 support	0.750	25, 26, 26	70, 73, 73	(10), (9), (3) (20), (8), (7)
951	[illegible]	Pt/Al2O3 type 1 support	0.750	0, 0	0, 0	<2, 2
952	[illegible]	Pt/Al2O3 type 1 support	0.750	0, 0	0, 0	0, 0

(Continued)

Table 133 (Contd-2). HIGH DENSITY FORMULATION WITH VARIOUS CATALYSTS IN MIXER: RUNS 1058-1062

Run No.	Catalyst Number	Description	Wt. %	5 min Compression, lbs		
		Type and Size		Maximum	Minimum	Average
1057	10850-105A	45 Pb[1]/Type 1 support	0.751	37, 37, 36	36, 36, 35	36, 36, 35
1058	10850-105B	45 Pb/Type 1 support	0.737	37, 36, 37	36, 36, 36	36, 36, 36
1059	10850-105C	45 Pb[1]/Type 1 support	0.744	38, 37, 37	37, 36, 37	38, 36, 37
1060	10850-105D	Bimetallic, 2. 5.4% type 1 support	0.748	4, 4, 3	3, 3, 3	3, 3, 3
1061	10850-105E	Bimetallic, 2. 5.4% type 1 support	0.738	4	3	3, 3, 3
1062	10850-105F	Bimetallic 45% 1061	0.743	3, 3	3	3, 3
1063	10850-6	5 45 metal/type 6 support	0.840	3, 3	3, 3	3, 3
1064	10850-106A	25 Pt, 5.8 type 1 support 5.8 type 1 support /45 type 6 binder	0.697	38, 37, 38	37, 36, 37	38, 36, 36
1065	8778-139	25 Pt/SCF 5-8 type Al_2O_3	0.691	39, 39, 38	38, 38, 38	39, 38, 38
1066	10850-106B	25 Pt, 45 type 1 support 5.8 type 1 support /45 type 6 binder	0.668	39, 38, 39	37, 37, 36	37, 37, 36
1067	10850-106C	45 Pt/type 1 support	0.638	39, 37, 38	37, 36, 36	38, 36, 37
1068	10850-106D	45 Pt, type 1 support	0.680	39, 39, 37	37, 36, 36	38, 38, 37
1069	10850-106E	Bimetallic, 5. 45/type 1 support	0.838	5, 5, 5	5, 5, 5	5, 5, 5
1070	10850-106F	Bimetallic, 5. 45/type 1 support	0.834	(2), (2) 17, 16, 17	37, 36, (3) 36, 38, 38	(38), (36), 36.[4] 36, 38, 37
1071	10850-106G	Bimetallic, 5. 45/type 1 support	0.838	3, 3, 3	37, 38, 3	38, 38, 37
1072	10850-106H	Bimetallic, 2. 25/type 1 support	0.755	23, 21, 19	35, 35, 33	(2), (2), (2)[4] 38, 37, 37
1073	10850-106I	Bimetallic, 2. 25/type 1 support	0.750	21, 22, 22	38, 38, 38	(6), (6), (6)[4] 38, 37, 35
1074	10850-106J	Bimetallic, 5. 5.4%/type 1 support	0.779	3, 3	3, 3	3, 3
1075	10850-106K	Bimetallic, 2. 25/type 1 support	0.804	27, 27, 25	31, 31, 31	(2), (2), (2)[4] 35, 35, 36
1076	10850-106L	Bimetallic, 5. 5.4%/type 1 support	0.786	26, 26, 25	36, 36, 36	(10), (2), (2)[4] 42, 41, 38
1077	10850-106M	45 Pt/mono support as for 1058	0.808	38, 35, 37	35, 34, 38	40, 39, 31
1078	1778	45 Pt/type 1 support (see attempt 1.35)	0.757	38, 36, 35	36, 35, 36	36, 35, 38
1079	8778-139	25 Pt/SCF 5-8 type Al_2O_3 (ref.)	0.695	38, 36, 36	36, 36, 36	37, 37, 37
1080	10850-106E	Bimetallic, 5. 45/type 1 support	0.771	17, 16, 19	38, 29, 29	(6), (6) 36, 36
1081	10850-106A	45 metal/type 1 support	0.761	29, 26, 26	(22), (2), (2) 36, 38, 38	(27), (25), (28) 61, 59, 58
1082	10850-106F	Bimetallic, 2. 45/type 1 support	0.788	17, 26, 26	35, 36, 36	(6), (2), (2) 38, 40, 39
1083	10850-106B	Bimetallic, 2. 45/type 1 support	0.789	26, 25, 28	36, 36, 36	(6), (6), (5) 62, 62, 62
1084	10850-106D	25 metal/type 1 support	0.721	23, 22, 7	28, 26, 26	23, 27, 25
1085	10850-106A	Bimetallic, 2. 45/type 1 support	0.788	20, 26, 22	29, 29, 29	23, 25, 25
1086	10850-106G	Bimetallic, 2. 25/type 1 support	0.772	13, 22, 10	28, 29, 28	(2), (2), (2) 30, 25, 26
1087	10850-106C	Bimetallic, 2. 25/type 1 support	0.763	22, 9, 9	25, 25, 25	28, 25, 23
1088	10850-106D	Bimetallic, 2. 25/type 1 support	0.754	25, 26, 22	63, 63	(6), (2), (2) 56, 56, 55
1089	10850-106E	Bimetallic, 2. 25/type 1 support	0.764	22, 22, 5	26, 27, 26	25, 25, 26
1090	10850-106F	Bimetallic, 2. 25/type 1 support	0.759	20, 9, 8	27, 25, 25	20, 22, 19
1091	10850-106	Bimetallic, 2. 5.4%/type 1 support	0.664	50, 28, 28	58, 50, 51	72, 72, 70
1092	10850-106A	25 metal/type 1 support	0.672	20, 25, 28	35, 35, 36	(5), (5), (5) 65, 65, 66
1093	8778-139	25 Pt/SCF 5-8 type Al_2O_3 (ref.)	0.695	25, 28, 27	51, 48, 47	73, 72 72
1094	10850-106G	Bimetallic, 2. 25/type 1 support	0.765	12, 8, 9	28, 26, 22	20, 19, 22
1095	10850-106B	Bimetallic, 2. 25/type 1 support	0.788	26, 32, 29	51, 51, 50	(2), (2), (2) 72, 72, 70
1096	10850-105A	45 Pt[1]/type 1 support	0.648	35, 30, 29	57, 56, 56	69, 69, 61
1097	10850-105B	45 Pt[1,2]/type 1 support	0.698	32, 28, 29	46, 46, 45	68, 68, 68
1098	10850-105C	25 metal[1]/ type 1 support	0.781	27, 27, 27	57, 55, 51	78, 77, 75
1099	10850-105D	25 metal[1,2]/type 1 support	0.784	30, 30, 32	55, 55, 57	(13), (2), (2) 60, 73, 78
1100	10850-105E	25 metal[2]/type 1 support	0.751	32, 25, 26	39, 35, 36	(15), (7), (7) 55, 56, 65
1101	10850-105F	25 metal[1,2]/type 1 support	0.761	25, 25, 21	40, 38, 37	(30), (22), (19) 66, 57, 58
1102	10850-106A	10850-105[1]	0.713	12, 20, 17	33, 29, 28	48, 44, 44
1103	10850-106B	10850-105[1,2]	0.718	17, 17, 13	38, 29, 26	(13), (5), (2) 46, 41, 46

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Table 133 (Cont'd-3). HCH HYDROGENATION WITH VARIOUS CATALYSTS IN MULTI-RUNS 1000-1000

Run No.	Catalyst Number	Catalyst Description	Wt., g	% HCH Conversion, Hr		
				[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1% Pt/SiO2 0-8 type Al2O3 (ref.)	0.438	77, 84, 88	90, 96, 98	98, 99, 71
1360	[illegible]	.5 Pt/type 1 support	1.897	85, 89, 89	89, 97, 96	75, 79, 99
1361	[illegible]	1% Pt/SiO2 0-8 type Al2O3 (ref.)	0.435	77, 85, 85	91, 97, 96	73, 71, 99
1362	10860-1362	.25 Pt/.5% type 1 support .5% type 1 support /2% type 6 binder	0.391	84, 85, 85	98, 90, 99	82, 84, 79
1363	10860-1363	.5 Pt/.5% type 1 support .5% type 1 support /2% type 6 binder	0.438	88, 98, 90	98, 99, 99	96, 89, 88
1364	10860-1364	.25 Pt/.5% type 1 support .5% type 1 support 2% type 6 binder	0.489	85, 86, 87	96, 99, 96	86, 80, 89
1365	10860-1365	.5 Pt/.5% type 1 support .5% type 1 support /2% type 6 binder	0.465	84, 98, 98	91, 98, 99	98, 98, 79
1366	[illegible]	1% Pt/SiO2 0-8 type Al2O3 (ref.)	0.432	77, 86, 85	92, 98, 96	73, 73, 72
1367	10860-	.25 Pt/.5% type 1 support[a][b] .5% type 1 support /2% type 6 binder Tube No. 16		85, (85), 85	99, 98, 97	79, 98, 99
1368		Above tube No. 16 filled with Cat. [illegible] is catalyst e_e	0.455			
1369	10860-1369	.25 Pt/.5% type 16 support .5% type 1 support /2% type 6 binder	0.509	85, 85, 83	95, 91, 93	82, 82, 82
1370	10860-1370	.25 Pt/.5% type 16 support .5% type 1 support /2% type 6 binder	0.568	89, 87, 87	96, 96, 96	88, 85, 79
1371	10860-1371	.25 Pt/.5% type 16 support .5% type 1 support 2% type 6 binder	0.485	87, 85, 81	96, 97, 98	79, 96, 96
1372	10860-1372	.25 Pt/.5% type 16 support .5% type 1 support /2% type 6 binder	0.490	80, 88, 89	99, 99, 93	88, 85, 85
1373	10860-1373	.5 Pt/.5% type 16 support .5% type 1 support /2% type 6 binder	0.539	96, 98, 89	98, 95, 95	98, 82, 85
1374	10860-1374	.25 Pt/.5% type 16 support .5% type 1 support /2% type 6 binder	0.564	89, 86, 87	96, 95, 95	85, 85, 86
1375	10860-1375	.25 Pt/.5% type 16 support /5% type 1 support /2% type 6 binder	0.585	86, 86, 87	97, 98, 98	84, 82, 88
1376	10860-1376	.25 Pt/.5% type 16 support .5% type 1 support /2% type 6 binder	0.588	85, 88, 88	98, 98, 98	79, 96, 98
1377	10860-7	Tube No. 16 coated with: 5.0% Pt/SiO2 type 1 support[d] /.5% type 1 support /2% SiO2		85, 93, 98	99, 98, 97	79, 98, 98
1378	10860-7	Tube No. 16 coated with: 5.0% Pt/SiO2 type 1 support /.5% type 1 support /2% SiO2 Heated in air		97, 86, 96	99, 99, 98	88, 82, 86
1379	10860-7	Tube No. 16 coated with 5.0% Pt/SiO2 type 1 support /.5% type 1 support /2% SiO2 After exp. 1377 Catalyst chamber filled with equal charge of reference catalyst	0.4388	95, 95, 96	65, 69, 68	88, 98, 92
1380	[illegible]	.25 Pt/SiO2 0-8 type Al2O3 (ref.)	0.432	87, 88, 86	96, 97, 96	73, 73, 79
1399	10860-1358	16 Pt[f]/type 1 support	0.751	96, 96, 88	93, 99, 95	88, 86, 88
1380	10860-1358	16 Pt[g]/type 1 support	0.460	97, 97, 95	98, 96, 98	88, 85, 85

a) Underlined numbers 5 hexanes, underscored numbers 5 conversion of HCH to benzene and toluene.
b) Muffled in air at 1197°F before reaction in H_2.
c) Support with 5.0% metal dried at 250°F before impregnation with the noble metal.
d) Support with 5.0% metal muffled at 1200°F in air.
e) 1857 ml.
f) 4 ml removed from the support.
g) Different heterogeneously mixed tubes used for comparable catalysts.
h) Muffled in air at 1000°F.
i) Compressed with No. 20 mesh.
j) Muffled in air at 1250°F.
k) Impregnated with 2.5% chloroplatinic.
l) Impregnated with ethylene diamine.
m) Impregnated metal, neutralized.
n) Muffled in air at 1200°F.
o) Bonds of Run No. 730 - Table).
p) Quartz filled.
q) Originally used in Run 730.
r) Single impregnation.
s) Four successive impregnations, first three thermal decomposition at 750°F, after each impregnation.

Measurement of Deposits on Coker Tubes With Nuclear Radiation[a)]

Presented here is a summary to date of the results and thoughts that have gone into the application of nuclear radiation as a tool for the evaluation of coker tube deposits. Covered are the general principles, electron scattering theory, preliminary experiments, trial apparatus and results, and proposed permanent instrument design. Electron backscatter appears to be the most promising approach and is the method of primary concern in the work presented here.

Thin Film Measurement With Nuclear Radiation General Principles

Thin film measurement with nuclear radiation can be accomplished either by transmission or scatter of the radiation. The problem is to select the best type and energy of radiation and guidelines to such selection that are available.[56)57)] The deposits of interest have a surface density in the neighborhood of 10^{-5} g/cm^2 equivalent to an air path of only .01 cm. This implies an arrangement based on scattering rather than absorption and the probable need of vacuum operation. Possible types of radiation applicable in the present case are summarized in the table below.

Table 134. METHODS OF UTILIZING NUCLEAR RADIATION

Type	Source Radiation	Detected Radiation	Operation	Remarks
1	α	α	alpha backscatter	Low scattering coefficient, requires very high intensity source.
2	α	x	x-ray fluorescence in coker tube	Possible method. Efficiency very dependent on tube metal.
3	β	β	beta backscatter	Preferred method.
4	β	x	x-ray fluorescence	Similar to method 2.
5	x	x	x-ray backscatter	Low efficiency.
6	x	x	x-ray fluorescence	Low efficiency.

The conclusion from this list is that electron scattering is preferred but other factors, not listed, also lead to the same conclusion. Should an alternative method be considered for investigation the use of fluorescence from alpha bombardment is probably the most promising. A transmission type of measurement is possible if radioactivity is introduced, by plating for example, onto the coker tube. This method, suggested by H. Siegel, is

a) Acknowledgement is made to Dr. R. Curtis of the Analytical Department for this work.

preferable from the point of view of measurement to any of those listed above, but the handling of radioactive tubes is a sufficient deterrent to exclude the method.

Electron Backscatter Theory

An approximate description of the relative backscattered electron flux to be expected from a coating of thickness x (g/cm^2) on a base of effectively infinite thickness is given by Tittle[38] as:

$$\frac{I}{I_o} = \frac{\beta_1}{\mu_1 + \lambda_1}\left[1 - e^{-(\mu_1+\lambda_1)x}\right] + \frac{\beta_2}{\mu_1 + \lambda_2}\, e^{-(\mu_1+\lambda_3)x} \qquad (53)$$

The constants μ, λ, and β depend upon the materials involved and the maximum beta energy, subscripts 1 and 2 referring to the coating and base respectively, and 3 to properties of both. From relations given by Tittle equation (53) in the approximation of small x can be expressed as:

$$\frac{I}{I_o} = \left(1 - e^{-Z_2/40}\right) + \frac{35x}{E^{1.14}}\left[\left(\frac{Z_1}{A_1}\right)\left(\frac{331 + Z_1}{106 + Z_1}\right)\left(1 - e^{-Z_1/40}\right) - \left(\frac{Z_1}{A_1} + \frac{50Z_1^{0.31}}{106 + Z_2}\right)\left(1 - e^{-Z_2/40}\right)\right] \qquad (54)$$

in which Z_1 and A_1 are the atomic number and atomic mass of the coating, Z_2 the atomic number of the substrate, and E is the maximum beta energy in Mev. Approximating the deposit composition by $Z_1/A_1 = 0.56$ and $Z_1 = 5.9$ on an aluminum ($Z_2 = 13$) base gives

$$\frac{I}{I_o} = 0.28 - \frac{4.4\,x}{E^{1.14}} \qquad (55)$$

as the ratio of scattered to incident flux. The statistics of counting and the general level of instrumental variables is such that it is not practical to measure a change dI/I_o of much less than 1%. Equation (55) then predicts a maximum energy of 1.1 Kev in order to detect a thickness change dx of 10^{-6} cm, assuming unit density for the deposit. Some idea of the range of thickness measurable with this energy is obtained by equating (55) to zero with the result $x = 3.10^{-5}$ g/cm^2. This prediction indicates the need of a very low energy source though perhaps not as low as 1 Kev if the expected range of thickness (up to 10^{-4} cm) is to be covered. Possible sources that are available are listed in Table 135. None of these sources is as low in energy as might be desired, but the least energetic sources should provide a useable compromise since even ^{14}C is capable of showing some response to the heavier deposits.

Table 135. LOW ENERGY BETA SOURCES

Isotope	Half Life, Years	Emax., Kev	Range in Air, cm
^{210}Pb	21	17	0.4
^{3}H	12	19	0.5
^{63}Ni	85	67	5.9
^{14}C	5700	155	26.0

Though not immediately apparent, equation (54) dicts that the replacement of aluminum with any metal of higher atomic number will produce an increased response to a given deposit. The method depends on the difference, primarily in atomic number, between coating and base. This difference is not large with aluminum so that a successful measurement in this case assures success with heavier metals.

Preliminary Experiments

Initial tests were aimed at answering three questions: whether operation without a vacuum was feasible, whether to minimize absorption a windowless flow counter was practical, and what magnitude of response would be observed in practice To this end a small counter was constructed (courtesy A. Telfer) from one inch brass tubing with a wedge shaped end opening approximately one mm wide. As a source ^{63}Ni, having a reasonable penetration in air, was utilized in the form of the chloride adsorbed on a strip of filter paper mounted near the counter entrance. Tests were made using a 3/16" aluminum rod covered with various thicknesses of mylar film and mounted 1/2 cm from the counter.

This arrangement was unsatisfactory in several respects. One difficulty, not unexpected, was a large dependence of count rate upon counter gas flow rate. This could be controlled, but drift beyond this factor occurred that could not be accounted for. Stability was sufficient to show a count difference for one mil mylar film but was wholly inadequate for the detection of deposit films. In short, it was concluded that vacuum operation, which would require a thin window counter, was necessary and that a lower energy beta source was essential.

Trial Apparatus and Results

The bell jar and forepump portion of a vacuum deposition apparatus were utilized in the following measurements. Feedthroughs in the base were provided for piping the flow of counter gas, the high voltage lead to the detector, and a slide fitting to which the collar tube could be attached. This slide fitting allowed translation and rotation of the outer tube in front of the source and detector for scanning the deposit area.

A locally constructed thin window flow counter[a] was used as detector. This window is exposed via a 3/32 x 5/8" slot cut in a one inch diameter faceplate. The source was mounted directly on this face about 1/4" from the slot. The source itself was a 1/8 x 1/4" section of a neutron generator targe arranged with a rather simple collimator fashioned from aluminum foil. The source-to-scatterer and scatterer-to-detector distance was 2.5 cm.

The associated electronics consisted of a Baird-Atomic Model 530 Spectrometer and Printer which provides the necessary functions of high voltage supply, pulse amplifier, discriminator, counter, and timer. Originally the high voltage was carried into the vacuum to the detector through a shielded cable, but this proved unsatisfactory. Attempts at shielding and insulating were not sufficient to eliminate corona and discharge in the vacuum with resultant spurious counting. A sufficiently hard vacuum to eliminate this problem was not practical. Instead, the high voltage lead and connection to the detector were enclosed in copper tubing and arranged to remain at atmospheric pressure.

The beta source used produces as well, some x-rays. These contribute to the scattered flux which is detected and produce a background counting rate even at atmospheric pressure. As the air pressure is reduced, a point is reached where the mean free path of the scattered electrons is sufficient for them to reach the detector and be counted. It was anticipated that a maximum count rate would be reached at some pressure and that this rate would remain constant below this pressure where essentially all electrons that could be scattered toward the detector would reach it. Instead, it was found that the count rate reached a maximum and then decreased with increasing vacuum. This maximum occurred at a pressure of approximately 25 torr while below 1/2 torr the count rate was independent of pressure. Apparently, as the pressure is reduced there is a maximum in count rate when the coker tube, bell jar wall, and residual atmosphere all contribute to the scattering and further evacuation diminishes the air scatter more rapidly than the increased scatter from wall and coker tube. As long as the pressure remains under 1/2 torr this presents no difficulty.

The coker tubes used in this study are of a miniature variety, the section of interest being 2-1/2" long and 1/8" diameter between end sections of 3/16" diameter. The deposit generally covers only a portion of the central tube section, being lightest (visually) near one shoulder, increasing in darkness toward the center of the tube and ending fairly abruptly to leave apparently bare metal beyond this point. The scattered intensity measured along such a tube is shown in Figure 83. Each point in the figure represents a 20 second count. The scatter of these points from a smooth curve is primarily due to statistical variations in counting. The rate corresponding to an uncoated tube is about 300 c/s, while on the wider tube section beyond the shoulder it is approximately 350 c/s. While the deposit in this example is a rather heavy one by visual inspection there appears to be ample sensitivity in the backscatter response. This is particularly true considering two simple improvements that could easily be introduced. The first involves better collimation of the incident beta flux to improve resolution of the

a) A. Telfer, "A Flow-Proportional Counter for Soft x-Rays", Emeryville Technical Progress Report 271-64.

deposit profile, the present arrangement viewing about 1/2 cm of tube at a time. The second improvement incorporates a collimator over the detector window the purpose of which is to reduce background scatter from the bell jar. This background involves both x-ray and electron scatter and amounts to about 100 c/s in the absence of a sample tube.

Results with a group of coker tubes are given in Figure 84. Again a 20 sec count was made at each point, but with the limited number of points involved a good approximation to the profile is acquired in roughly 3 min. The two curves for each sample are scans along opposite sides of the tubes. The horizontal line to the right of each curve is an adjusted rate of 300 c/s. This adjustment was necessary because of an unexplained drift, possibly arising from the electronics, which could be corrected for each scan by returning to the starting position, but which is more difficult to correct for in going from tube to tube.

Calibration points for establishing a thickness scale were obtained using mylar film and by coating a tube with films of solution cast nitrocellulose. The mylar film (1/8 mil) is approaching infinite scattering thickness which simply means that the aluminum rod no longer contributes to the scattering. At this point the count rate has dropped from 300 to 200 c/s. Reasonably consistent results were obtained with 1, 2 and 4000A of film. Applied to the five tubes in Figure 84 this gives the following results as shown in Table 136.

$$\frac{I}{I_o} = 1 - e^{-Z_2/40} + \frac{35x}{E^{1.14}}\left[\frac{Z_1}{A_1}\left(\frac{331 + Z_1}{106 + Z_1}\right)\left(1 - e^{-Z_1/40}\right) - \left(\frac{Z_1}{A_1} + \frac{400\ Z_1^{0.31}}{106 + Z_2}\right)\left(1 - e^{-Z_2/40}\right)\right]$$

For Aluminum base $Z_2 = 13$ $\quad x$ = film thickness, g/cm^2

$$\frac{I}{I_o} = 0.2775 + \frac{35x}{E^{1.14}}\left[\frac{Z_1}{A_1}\left(\frac{331 + Z_1}{106 + Z_1}\right)\left(1 - e^{-Z_1/40}\right) - \left(\frac{Z_1}{A_1} + 4.195\ Z_1^{0.31}\right)(0.277/4)\right]$$

Composition		Z_1	Z_1/A_1	$Z_1^{0.31}$	$1 - e^{-Z_1/40}$	$[<0]$	% Change[a]
CH	= 7.74w% H	5.613	.5383	1.707	.1309	1.914	-
CH_2	= 14w% H	5.28	.572	1.675	.1237	1.898	-2.0
$CHO_{.25}$	= 23.5w% O	6.18	.529	1.758	.1432	1.965	+1.5
$CHS_{.05}$	= 11w% S	6.75	.534	1.808	.1553	2.005	+3.5
$CHFe_{.01}$	= 4.1w% Fe	6.46	.535	1.784	.1492	1.985	+2.5
$CHPb_{.001}$	= 1.4w% Pb	6.64	.519	1.798	.1530	1.997	+3.1

a) Scaled with CH as reference.

Z = at. no.

A = Avg at. wt. of coating

w = wt. fraction

E = max energy of source, MEV

$Z_1 = \Sigma w_i Z_i$

$\frac{Z_1}{A_1} = \Sigma w_i \frac{Z_i}{A_i}$

Tritium = .019 (must be a very soft source)

Table 136. RESULTS ON FIVE COKER TUBES

Fuel No.	Max Count Rate Decrease	Max Film Thickness, A°	Approx Total[a] Deposit, A° x cm	Visual Ratings	
				Max	Avg
1	85 c/s	5000	6000	7.0	1.3
2	70	4500	7000	6.5	1.5
3	20	1200	1500	4.0	1.6
4	50	3000	4000	6.5	1.8
5	125	8000	6000	6.5	1.0

a) Multiplication by tube circumference (1.0 cm) will give total deposit volume.

There is little agreement with the visual ratings. The scattering results are, of course, reproducible and independent of operator judgment.

The deposit composition in calculations with equation (54) was assumed to be $CH_2O_{.25}$. It can approach $CHO_{.25}$ and may contain up to 5% sulfur. Again the effects of composition changes in the deposit on the scattered intensity can be estimated at least roughly from this equation. The main effect from composition changes is in the average for Z. Starting with $CH_2O_{.25}$ and going to $CH_2O_{.25}S_{.05}$, that is, adding 8% sulfur is equivalent to a 2% change in apparent thickness. The dependence on sulfur or any other heavier element is large, as expected, but film measurement within 2% that does not depend on composition is still far superior to visual estimates.

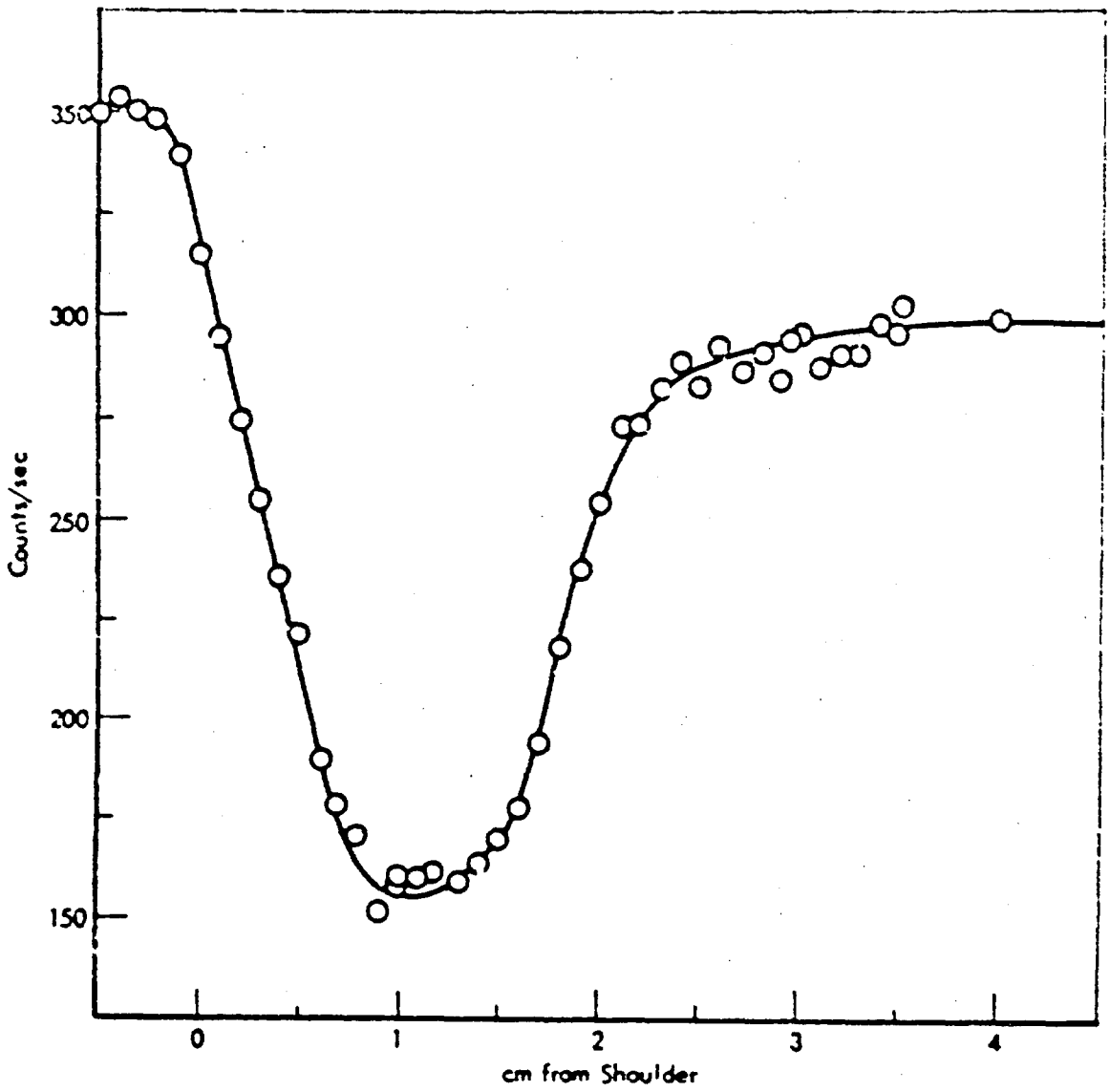


Figure 83. COKER TUBE DEPOSIT PROFILE

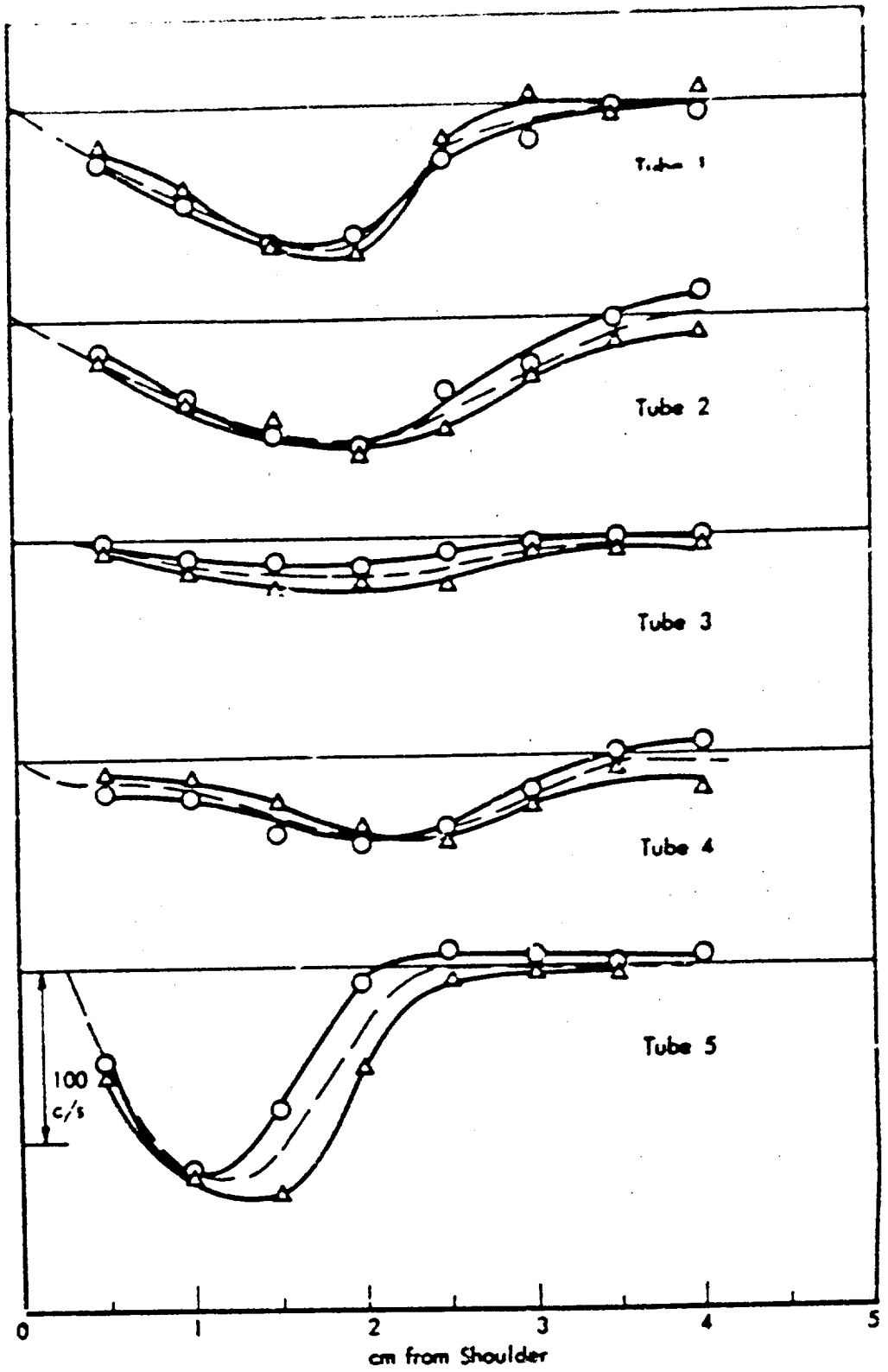


Figure 84. COMPARISON OF DEPOSIT TUBE PROFILES

Proposed Instrument Design

The results observed above demonstrate the feasibility of electron backscatter as a means of quantitative measurement of coker tube deposits. Several conveniences can, however, be incorporated in a practical instrument. These include automatic scanning and recording of the profile and a convenient vacuum assembly.

In respect to scanning it may be convenient to integrate or average readings around the tube circumference so that a one-dimensional average along the tube length is obtained. This can be achieved in either of two ways. With a point source and detector arrangement and a ratemeter output the tube can be rotated with a period less than the time constant of the ratemeter while being translated along its length. A motor driven screw motion would achieve this. The alternative is to arrange both source and cylinder in the form of rings surrounding the rod. Actually, a triangular array would provide a sufficient approximation to a continuous ring. The main cost increase would be in respect to three detectors. The source and electronics cost increase is trivial. In this way only a linear motion need be applied to the sample tube and eccentricity is averaged out.

For the vacuum assembly it may be most convenient to adapt a commercially available apparatus involving a bell jar. But a smaller volume would allow quicker pumping down and would be more compact. This could be in the form of a tube sufficiently long for sample translation and of perhaps 3" ID. An external motor drive would move the sample placed on a suitable carriage. Source and detector would be mounted in the mid-section wall of the tube with collimation on the source and on the detector to reduce extraneous backscatter. Electrical connections would then all be at atmospheric pressure.

TABLE 37B
CHARACTERISTIC PROPERTIES OF DECALIN
(.948 CIS, .900 TRANS)

MOLECULAR WEIGHT	138.2	138.2
ACENTRIC FACTOR	.299	.299
CRITICAL PRESSURE	30.7 atm	31.8 PSIA
CRITICAL TEMPERATURE	413.8 C	776.2 F
CRITICAL COMPRESSIBILITY FACTOR	.267	.267
CRITICAL DENSITY	.296 GM/CC	18.466 LB/CUFT
FREEZING POINT	-44.8 C	-48.2 F
NORMAL BOILING POINT	188.8 C	372.3 F
NORMAL ENTHALPY OF VAPORIZATION	87.8 CAL/GM	157.8 BTU/LB
HEAT OF FORMATION	18148. CAL/GM	18898. BTU/LB

TABLE 38
LIQUID PROPERTIES OF DECALIN AT SATURATION
(.948 CIS, .900 TRANS)

TEMP, C	VAPOR PRESS, atm	ENTHALPY OF VAP, CAL/GM	ENTHALPY, CAL/GM	ENTROPY, CAL/GM-C	SPEC HEAT AT CONST P, CAL/GM-C	DENSITY, GM/CC*	VISCOSITY, CP	THERMAL COND, CAL/CM-SEC-C	PRANDTL NUMBER
-40	3.9710-04	8.9639+01	+1.2627+01	-1.0469-01	2.9975-01	9.2796+01	1.5501+01	3.7884+00	1.1873+02
-20	8.1617-04	8.8184+01	+6.8998+00	-5.8790-02	3.2966-01	9.1125+01	7.5713+00	3.7197+00	6.6981+01
0	1.6793-03	8.6677+01	0.0000	0.0000	3.4904-01	8.9487+01	4.2969+00	3.6619+00	4.3625+01
20	3.4098-03	8.5145+01	7.2722+00	4.7147-02	3.7017+01	8.7877+01	2.7019+00	3.6047+00	2.8639+01
40	7.0513-03	8.3587+01	1.5119+01	9.1420-02	4.0798+01	8.6288+01	1.8379+00	3.5474+00	2.0634+01
60	1.4097-02	8.1993+01	2.3068+01	1.3338-01	4.3636+01	8.4720+01	1.3302+00	3.4889+00	1.6481+01
80	2.7280-02	8.0358+01	3.1096+01	1.7394-01	4.6665+01	8.3167+01	1.0078+00	3.4314+00	1.3907+01
100	5.1573-02	7.8713+01	4.7736+01	2.1719-01	5.0118+01	8.1599+01	7.8494+01	3.4529+00	1.1932+01
120	1.2669-01	7.6918+01	5.2+.6+01	2.6934-01	5.3193+01	8.0013+01	6.4449+01	3.[illegible]	[illegible]+01
140	2.6460-01	7.4969+01	6.3106+01	2.8934-01	5.6687+01	7.8[illegible]+01	5.4819+01	3.3918+00	9.1798+00
160	4.9491-01	7.[illegible]+01	7.4526+01	3.2093-01	6.0528+01	7.7717+01	4.5969+01	3.2995+00	8.3683+00
180	8.9582-01	6.8889+01	8.6032+01	3.5478-01	6.5004+01	7.6197+01	3.8534+01	3.2494+00	7.6982+00
200	1.5538+00	6.6781+01	9.8766+01	3.8963-01	6.8969+01	7.4643+01	3.4498+01	3.1987+00	7.1435+00
220	2.6169+00	6.4527+01	1.1156+02	4.2594-01	7.3374+01	7.2864+01	2.9873+01	3.1494+00	6.6868+00
240	4.2559+00	6.[illegible]+01	1.2489+02	4.6242-01	7.8119+01	7.1230+01	2.5[illegible]+01	3.0927+00	6.1[illegible]+00
260	6.6871+00	5.[illegible]+01	1.3858+02	4.8361-01	7.7836+01	6.9187+01	2.1[illegible]+01	2.9714+00	5.9766+00
280	9.9020+00	5.2401+01	1.5271+02	5.1412-01	8.1483+01	6.7819+01	1.7733+01	2.8804+00	5.5163+00
300	8.6907+00	4.8933+01	1.6710+02	5.4369-01	8.5650+01	6.[illegible]+01	1.4899+01	2.7978+00	5.1604+00
320	1.1271+01	4.6228+01	1.8229+02	5.7323-01	9.0017+01	6.2100+01	1.2913+01	2.6994+00	4.8143+00
340	1.4291+01	3.9438+01	1.9754+02	6.0729-01	9.7109+01	5.9903+01	1.0480+01	2.6311+00	4.4944+00
360	1.7634+01	3.3895+01	2.1306+02	6.3124-01	1.0799+00	5.5420+01	8.7458+02	2.5621+00	4.2283+00
380	2.1429+01	2.8699+01	2.3087+02	6.6674-01	1.2400+00	5.1408+01	7.1789+02	2.4834+00	3.9783+00
400	2.5634+01	1.6912+01	2.4988+02	6.9184-01	1.8211+00	4.8916+01	5.5449+02	3.8309+00	3.3221+00

LIQUID PROPERTIES OF DECALIN AT SATURATION
(.948 CIS, .900 TRANS)

TEMP, F	VAPOR PRESS, PSIA	ENTHALPY OF VAP, BTU/LB	ENTHALPY, BTU/LB	ENTROPY, BTU/LB-R	SPEC HEAT AT CONST P, BTU/LB-R	DENSITY, LB/CUFT	VISCOSITY, LB/FT-HR	THERMAL COND, BTU/FT-HR-F	PRANDTL NUMBER
-40	4.7692-03	1.6208+02	+1.9183+01	-7.7469-02	2.8919-01	9.8108+01	4.6483+01	9.1997-02	1.6367+02
0	1.2993-02	1.5845+02	0.0000	0.0000	3.2379-01	9.6913+01	1.7995+01	9.0334+02	6.1758+01
32	3.5499-02	1.5446+02	1.7187+01	6.8660-02	3.6193-01	9.5434+01	8.1913+00	8.8736+02	3.3774+01
100	9.8211-02	1.5374+02	9.6366+01	1.3193-01	4.2494-01	9.4343+01	4.6747+00	8.7191+02	2.1668+01
150	2.7172-01	1.4658+02	1.7569+01	1.8960-01	4.6495-01	9.3000+01	2.9625+00	8.5992+02	1.5476+01
200	7.3858-01	1.4139+02	8.0906+01	2.4437-01	4.9858-01	9.1735+01	2.0729+00	8.3922+02	1.2112+01
250	1.9338+00	1.3697+02	1.8819+02	2.9828-01	5.3536-01	9.0398+01	1.5477+00	8.2758+02	1.0074+01
300	4.7644+00	1.3133+02	1.3546+02	3.4998-01	5.8146-01	8.9056+01	1.2147+00	8.0922+02	8.7719+00
350	1.0809+01	1.2481+02	1.8273+02	3.8606-01	6.2687+01	8.7758+01	9.7699+01	7.8736+02	7.7919+00
400	2.2162+01	1.1777+02	1.9136+02	4.4022-01	6.7764+01	8.6307+01	7.9736+01	7.6613+02	7.0329+00
450	4.0994+01	1.6985+02	2.2811+02	4.8561-01	7.2732+01	8.4797+01	6.5927+01	7.4536+02	6.3666+00
500	6.9829+01	1.0115+02	2.6623+02	5.2951-01	7.7436+01	8.3164+01	5.5993+01	7.1879+02	5.5286+00
550	1.0739+02	9.1717+01	2.9979+02	5.7368-01	8.3079+01	8.1382+01	4.8968+01	6.8744+02	6.8444+00
600	1.5671+02	8.1395+01	3.3240+02	6.1169-01	8.9686+01	7.9519+01	3.1668+01	6.5761+02	4.2917+00
650	2.1731+02	6.8423+01	3.7138+02	6.5194-01	9.9288+01	7.6679+01	2.6438+01	6.3699+02	3.8497+00
700	2.8648+02	5.4363+01	4.1229+02	6.9263-01	1.1873+02	7.3424+01	1.9819+01	6.3371+02	3.0832+00
750	3.7222+02	3.6470+01	4.9054+02	7.3449-01	1.7684+00	2.8125+01	1.3668+01	7.2383+02	3.3278+00

GAS PROPERTIES OF DRY AIR AT SATURATION
1 ATM DIA. .500 TRANS

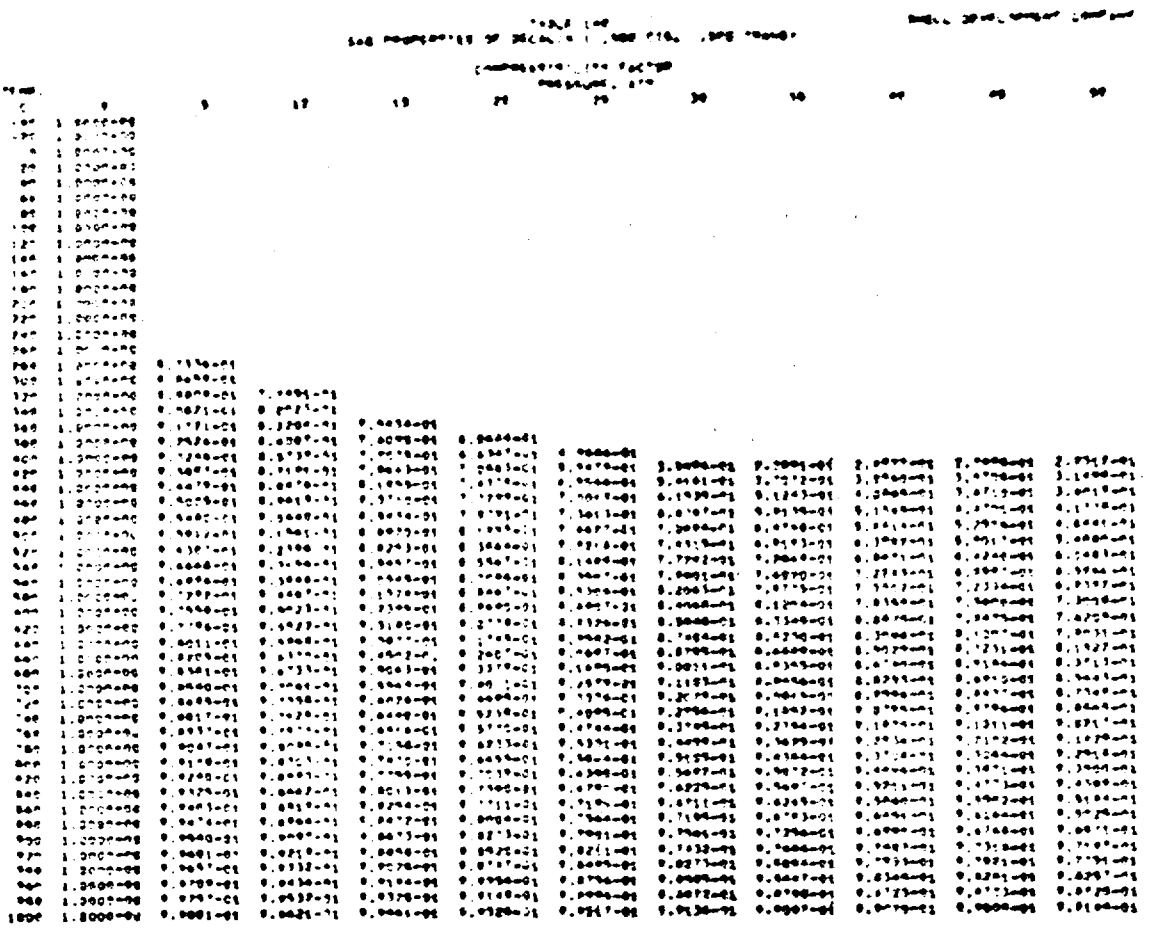
TEMP. C	VAPOR PRESS. ATM	DENS OF SAT'D V. GM/CC	RATIO OF SPEC HEATS	SONIC VEL. CM/SEC	VAP CONDY. CAL/CM-SEC-K	VISCOSITY CP	THERMAL COND. CAL/CM-SEC-K	PRANDTL NUMBER
-40	3.8716E-04	2.3414E-03	1.4018E+00	1.2791E+04	2.8291E-04	0.9716E-03	1.2713E-05	1.5897E+01
-30	8.1827E-04	2.3729E-03	1.4018E+00	1.2791E+04	2.8291E-04	0.9716E-03	1.5446E-05	1.8005E+01
-8	1.6795E-03	2.3974E-03	1.4018E+00	1.3116E+04	1.8124E-04	0.9 3.92E-03	1.8777E-05	1.9114E+01
25	3.6898E-03	2.4654E-03	1.4018E+00	1.3462E+04	1.2578E-04	0.9447E-03	2.1494E-05	1.9136E+01
40	7.3913E-03	3.1771E-03	1.4018E+00	1.4027E+04	0.8795E-04	0.9233E-03	2.4805E-05	1.9464E+01
60	1.5907E-02	3.1972E-03	1.4018E+00	1.4636E+04	0.6232E-04	0.9396E-03	2.8287E-05	1.9741E+01
80	3.1294E-02	3.6121E-03	1.4018E+00	1.5277E+04	0.5294E-04	0.9777E-03	3.1919E-05	1.9918E+01
100	6.3973E-02	3.8773E-03	1.4018E+00	1.5917E+04	0.3636E-04	1.0197E-03	3.5732E-05	2.0111E+01
120	1.2668E-01	4.2177E-03	1.4018E+00	1.6537E+04	0.4933E-04	1.0618E-03	3.9723E-05	2.0299E+01
140	2.4416E-01	4.3658E-03	1.4018E+00	1.7135E+04	0.3758E-04	1.0991E-03	4.3748E-05	2.0475E+01
160	4.6000E-01	4.8963E-03	1.4018E+00	1.7712E+04	0.3219E-04	1.1389E-03	4.7914E-05	2.0644E+01
180	8.5062E-01	4.8963E-01	1.4018E+00	1.8252E+04	2.7214E-05	8.0169E-03	5.2054E-05	2.0797E+01
200	1.5538E+00	5.4414E-01	1.4018E+00	1.8791E+04	2.3705E-05	9.2179E-03	5.7154E-05	2.0959E+01
220	2.7544E+00	5.2977E-01	1.4018E+00	1.9323E+04	2.0960E-05	9.4429E-03	6.1987E-05	2.1091E+01
240	3.2768E+00	5.9119E-01	1.4018E+00	1.9854E+04	1.8876E-05	9.6876E-03	6.6957E-05	2.1199E+01
260	4.6971E+00	5.7491E-01	1.4018E+00	1.9713E+04	1.7128E-05	1.0368E-02	7.1167E-05	2.1411E+01
280	6.5829E+00	5.9758E-01	1.4018E+00	1.9834E+04	1.6342E-05	1.0727E-02	7.7178E-05	2.1562E+01
300	8.6907E+00	6.1997E-01	1.4018E+00	1.9951E+04	1.5064E-05	1.1127E-02	8.2662E-05	2.1677E+01
320	1.1271E+01	6.4369E-01	1.4018E+00	1.2107E+04	1.5078E-05	1.1731E-02	8.8176E-05	2.1796E+01
340	1.4251E+01	6.6441E-01	1.4018E+00	1.2231E+04	1.6405E-05	1.2727E-02	9.4566E-05	2.1977E+01
360	1.7836E+01	6.9135E-01	1.4018E+00	1.2351E+04	1.0750E-05	1.3494E-02	1.0273E-04	2.2053E+01
380	2.1979E+01	7.2425E-01	1.4018E+00	0.7365E+03	2.1532E-05	1.5661E-02	1.0795E-04	2.2614E+01
400	2.5634E+01	8.1732E-01	1.4018E+00	7.1662E+03	3.0032E-05	1.8369E-02	1.1693E-04	1.8847E+00

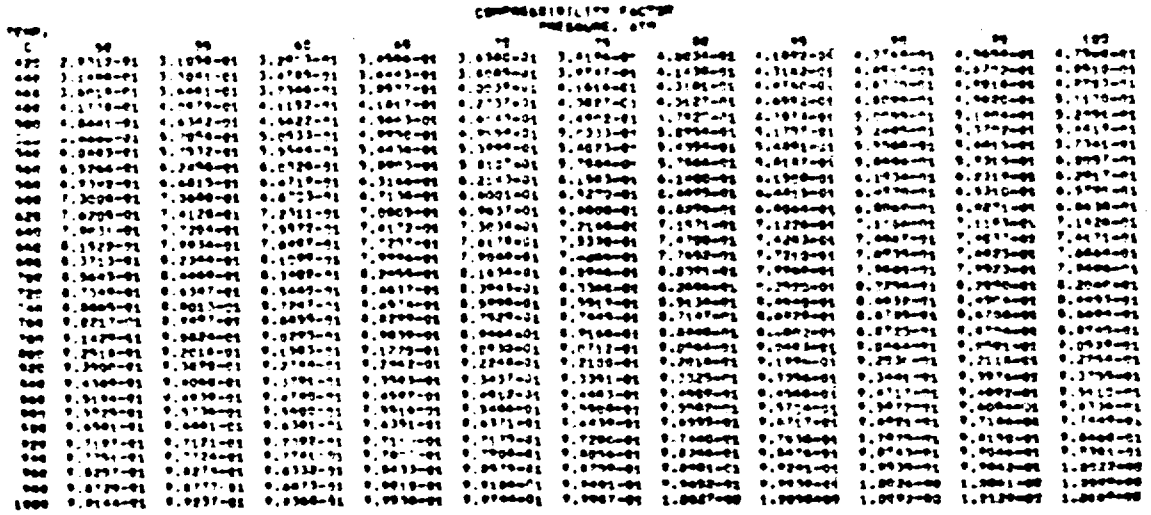
GAS PROPERTIES OF DRY AIR AT SATURATION
1 ATM DIA. .500 TRANS

TEMP. F	VAPOR PRESS. PSIA	DENS OF SAT'D V. LB/CU FT	RATIO OF SPEC HEATS	SONIC VEL. FT/SEC	VAP CONDY. BTU/HR-FT-F	VISCOSITY LB/FT-HR	THERMAL COND. BTU/HR-FT-F	SPEC HEAT AT CONST P, BTU/LB-F
-40	6.7062E-03	9.0543E-01	1.4018E+00	6.7660E+03	1.6034E-02	3.1813E-01	-3.1198E-07	2.1758E-01
0	1.2991E-02	9.0969E-01	1.4018E+00	1.2991E+04	1.9034E-02	3.4498E-01	-2.9616E-07	2.0075E-01
30	3.5000E-02	9.0969E-01	1.4018E+00	1.5460E+04	1.7185E-02	3.7279E-01	-2.7741E-07	2.0761E-01
100	9.0211E-02	9.0931E-01	2.2671E+03	9.8614E+02	1.0711E-02	4.2706E-01	-2.9286E-07	3.2028E-01
150	2.7172E-01	9.0846E-01	9.7502E+03	2.7131E+01	2.9013E-02	4.3002E-01	-2.3530E-07	3.9077E-01
200	7.3065E-01	9.0461E-01	1.4018E+03	7.3400E+01	2.2284E-02	4.5954E-01	-2.1539E-07	3.9414E-01
250	1.6230E+00	8.9761E-01	3.9360E+03	1.9586E+03	2.6311E-02	4.8922E-01	-1.9861E-07	4.2761E-01
300	4.7666E+00	8.8468E-01	8.2250E+02	4.6923E+03	2.6873E-02	5.1983E-01	-1.8197E-07	4.6114E-01
350	1.0005E+01	9.7304E-01	1.7722E-01	1.0000E+04	2.8754E-02	5.6021E-01	-1.7261E-07	4.9491E-01
400	2.2162E-01	9.6644E-01	3.5084E+01	2.1750E+04	3.1137E-02	5.7721E-01	-1.5807E-07	5.2859E-01
450	4.8994E-01	8.1237E-01	6.3623E-01	3.7668E+01	3.3304E-02	6.1970E-01	-1.4987E-07	5.6366E-01
500	6.9972E-01	8.0761E-01	1.2440E+00	6.0988E+01	3.0137E-02	6.3391E-01	-1.4044E-07	5.9847E-01
550	1.8739E+02	8.1274E-01	1.8459E+00	9.8314E+01	3.8747E-02	6.8153E-01	-1.3375E-07	6.3697E-01
600	1.5671E+02	7.4816E-01	2.5464E+00	1.2768E+02	4.1368E-02	6.8864E-01	-1.2564E-07	6.7818E-01
650	2.1731E+02	6.7336E-01	3.7464E+01	1.6422E+02	4.0091E-02	7.1394E-01	-1.2912E-07	7.2011E-01
700	2.8944E+02	5.8479E-01	5.6977E+00	2.0491E+02	4.6665E-02	7.3934E-01	-1.2716E-07	8.1518E-01
750	3.7713E+02	4.6387E-01	8.5693E+00	2.5304E+02	6.9822E-02	7.8114E-01	-1.2768E-07	1.1910E+00

GAS PROPERTIES OF DRY AIR AT SATURATION
1 ATM DIA. .500 TRANS

TEMP. F	VAPOR PRESS. PSIA	SPEC HEAT AT CONST V, BTU/LB-F	RATIO OF SPEC HEATS	SONIC VEL. FT/SEC	VAP CONDY. BTU/HR-FT-F	VISCOSITY LB/FT-HR	THERMAL COND. BTU/HR-FT-F	PRANDTL NUMBER
-40	6.7062E-03	1.9621E-01	1.4018E+00	3.7704E+02	3.7739E-02	1.0814E-02	2.9011E-03	7.6471E-01
0	1.2991E-02	2.3937E-01	1.4018E+00	4.1870E+02	2.3626E-03	1.2744E-02	3.8113E-03	7.9031E-01
30	3.5000E-02	2.7192E-01	1.4018E+00	4.3014E+02	1.7304E-02	1.3279E-02	4.8159E-03	7.9211E-01
100	9.0211E-02	3.0883E-01	1.4018E+00	4.9687E+02	1.2733E-02	1.4446E-02	5.9087E-03	7.9466E-01
150	2.7172E-01	3.6926E-01	1.4018E+00	4.7725E+02	9.2609E-01	1.5716E-02	7.0484E-03	7.9736E-01
200	7.3065E-01	3.7902E-01	1.4018E+00	4.9666E+02	7.0091E-01	1.6936E-02	8.3368E-03	8.0061E-01
250	1.9730E+00	4.1311E-01	1.4018E+00	5.1534E+02	5.4080E-01	1.8157E-02	9.6631E-03	8.0731E-01
300	4.7666E+00	4.6603E-01	1.4018E+00	5.2727E+02	4.2668E-01	1.9395E-02	1.1761E-02	8.2458E-01
350	1.0805E+01	4.7871E-01	1.4018E+00	5.3684E+02	3.4139E-01	2.0670E-02	1.2936E-02	8.1629E-01
400	2.2162E+01	5.1139E-01	1.4018E+00	5.3400E+02	2.6812E-01	2.2036E-02	1.4075E-02	8.2760E-01
450	4.8994E+01	5.4406E-01	1.4018E+00	5.2951E+02	2.4012E-01	2.3508E-02	1.5697E-02	8.4417E-01
500	6.9972E+01	5.7691E-01	1.4018E+00	5.1951E+02	2.1224E-01	2.5130E-02	1.7109E-02	8.6911E-01
550	1.8739E+02	6.0124E-01	1.4018E+00	5.0729E+02	1.9727E-01	2.6979E-02	1.8479E-02	8.9711E-01
600	1.5671E+02	6.3758E-01	1.4018E+00	4.9473E+02	1.9364E-01	2.9187E-02	2.1364E-02	9.3574E-01
650	2.1731E+02	6.7797E-01	1.4018E+00	4.8111E+02	2.0423E-01	3.1966E-02	2.3874E-02	1.0754E+00
700	2.8944E+02	7.1185E-01	1.4018E+00	5.4643E+02	2.0644E-01	3.0764E-02	2.8271E-02	1.1032E+00
750	3.7713E+02	8.8739E-01	1.4018E+00	2.4854E+02	3.6001E-01	4.3864E-02	2.7928E-02	1.0077E+00





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GAS PROPERTIES OF DECALIN (,90° CIS, .998 *MOLE)

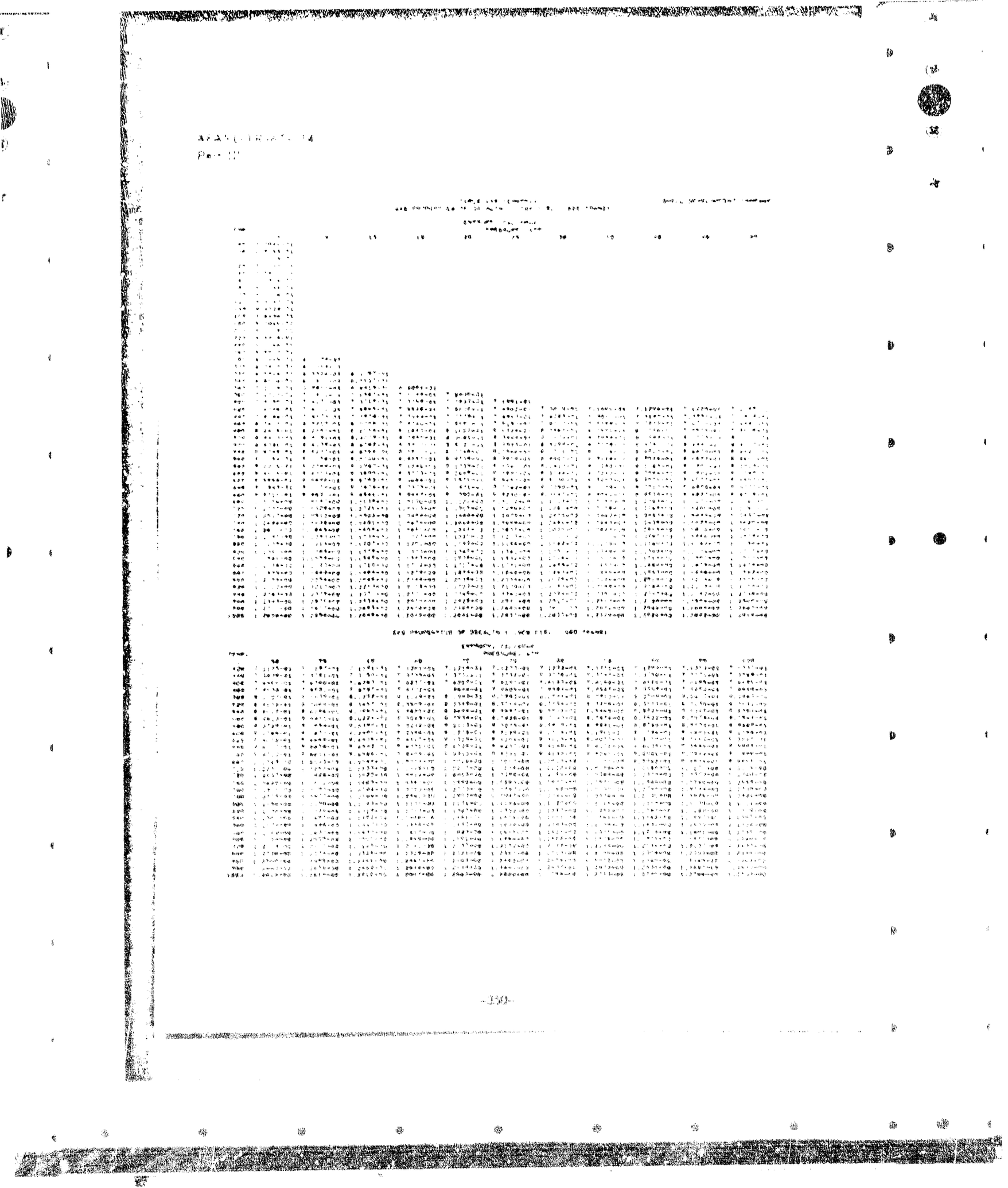
ENTHALPY, CAL/GM
PRESSURE, ATM

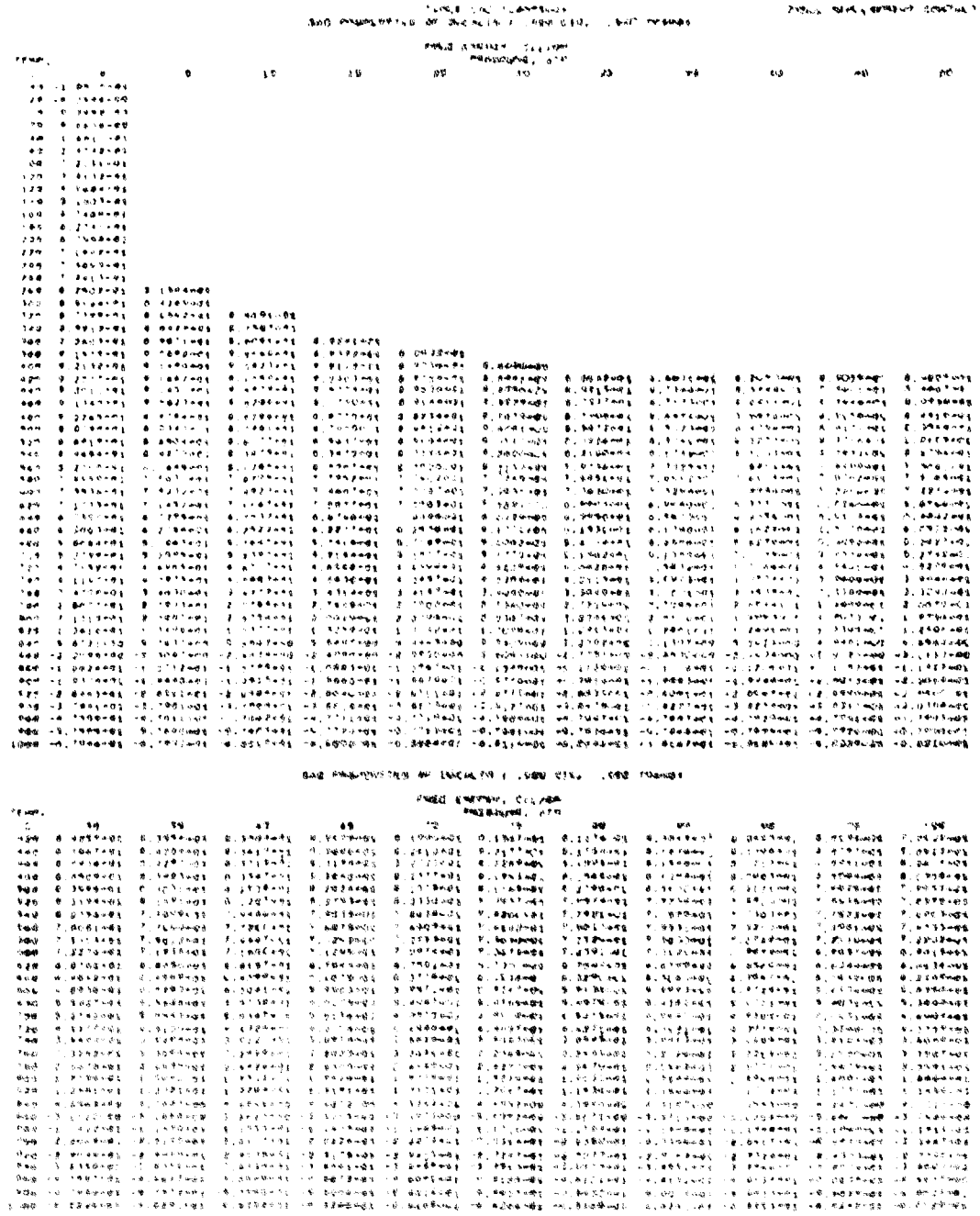
TEMP. K	1	5	10	15	20	25	30	40	50	60
400	7.9629E-01									
420	8.1167E-01									
440	8.2684E-01									
460	8.4179E-01									
480	8.5654E-01									
500	8.7110E-01									
520	8.8547E-01									
540	8.9966E-01									
560	9.1368E-01									
580	9.2753E-01									
600	9.4122E-01									
620	9.5475E-01									
640	9.6813E-01									
660	9.8136E-01									
680	9.9445E-01									
700	1.0074E+00	1.0668E+00								
720	1.0203E+00	1.0797E+00								
740	1.0331E+00	1.0925E+00	1.1576E+00							
760	1.0458E+00	1.1052E+00	1.1703E+00							
780	1.0585E+00	1.1178E+00	1.1829E+00	1.2532E+00						
800	1.0711E+00	1.1304E+00	1.1955E+00	1.2658E+00	1.3414E+00					
820	1.0836E+00	1.1429E+00	1.2080E+00	1.2783E+00	1.3539E+00	1.4346E+00				
840	1.0961E+00	1.1554E+00	1.2205E+00	1.2908E+00	1.3664E+00	1.4471E+00				
860	1.1086E+00	1.1679E+00	1.2330E+00	1.3033E+00	1.3789E+00	1.4596E+00	1.5454E+00			
880	1.1210E+00	1.1803E+00	1.2454E+00	1.3157E+00	1.3913E+00	1.4720E+00	1.5578E+00			
900	1.1334E+00	1.1927E+00	1.2578E+00	1.3281E+00	1.4037E+00	1.4844E+00	1.5702E+00	1.6611E+00		
920	1.1457E+00	1.2050E+00	1.2701E+00	1.3404E+00	1.4160E+00	1.4967E+00	1.5825E+00	1.6734E+00		
940	1.1580E+00	1.2173E+00	1.2824E+00	1.3527E+00	1.4283E+00	1.5090E+00	1.5948E+00	1.6857E+00	1.7818E+00	
960	1.1703E+00	1.2296E+00	1.2947E+00	1.3650E+00	1.4406E+00	1.5213E+00	1.6071E+00	1.6980E+00	1.7941E+00	
980	1.1825E+00	1.2418E+00	1.3069E+00	1.3772E+00	1.4528E+00	1.5335E+00	1.6193E+00	1.7102E+00	1.8063E+00	
1000	1.1947E+00	1.2540E+00	1.3191E+00	1.3894E+00	1.4650E+00	1.5457E+00	1.6315E+00	1.7224E+00	1.8185E+00	1.9146E+00

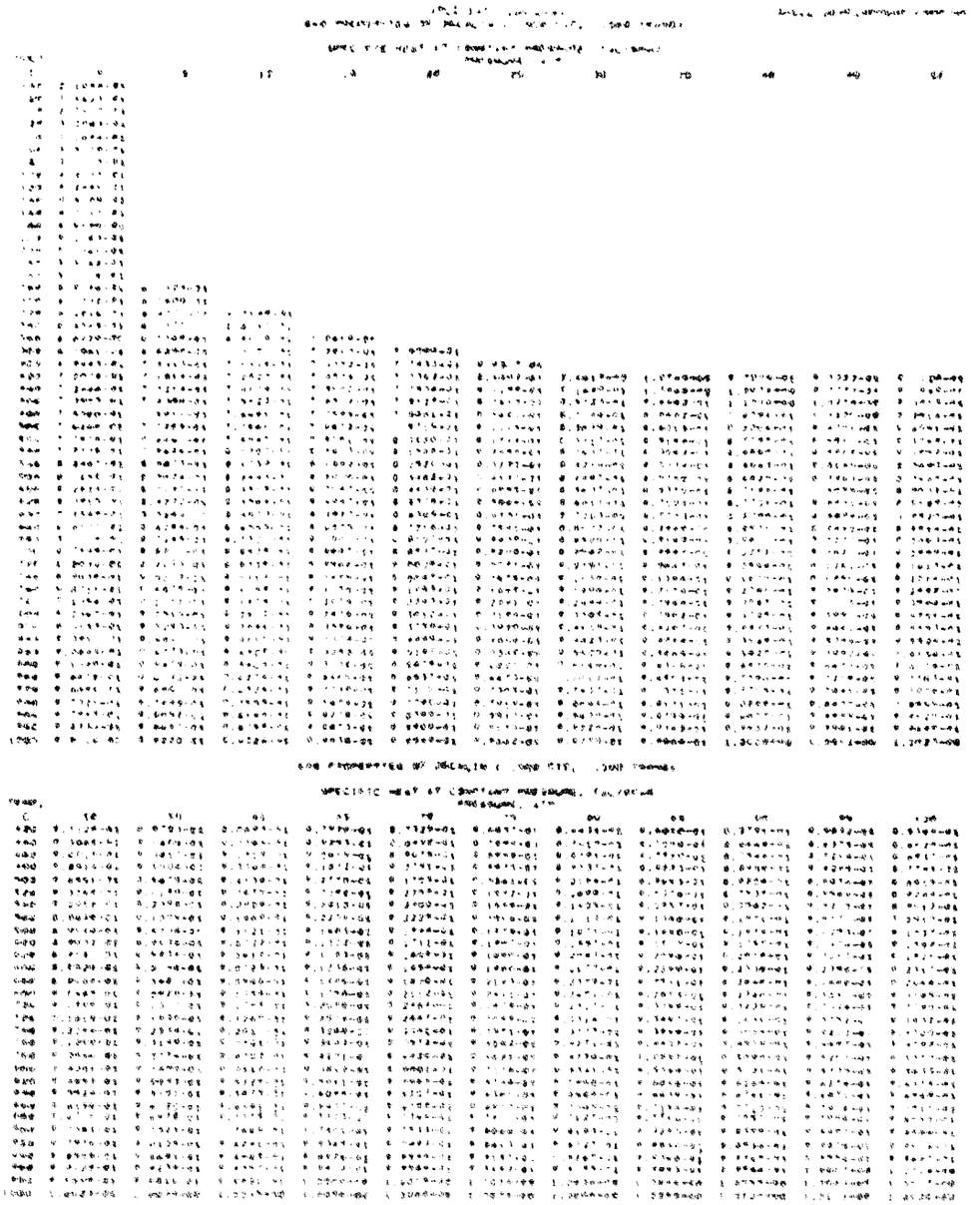
GAS PROPERTIES OF DECALIN (,90° CIS, .998 *MOLE)

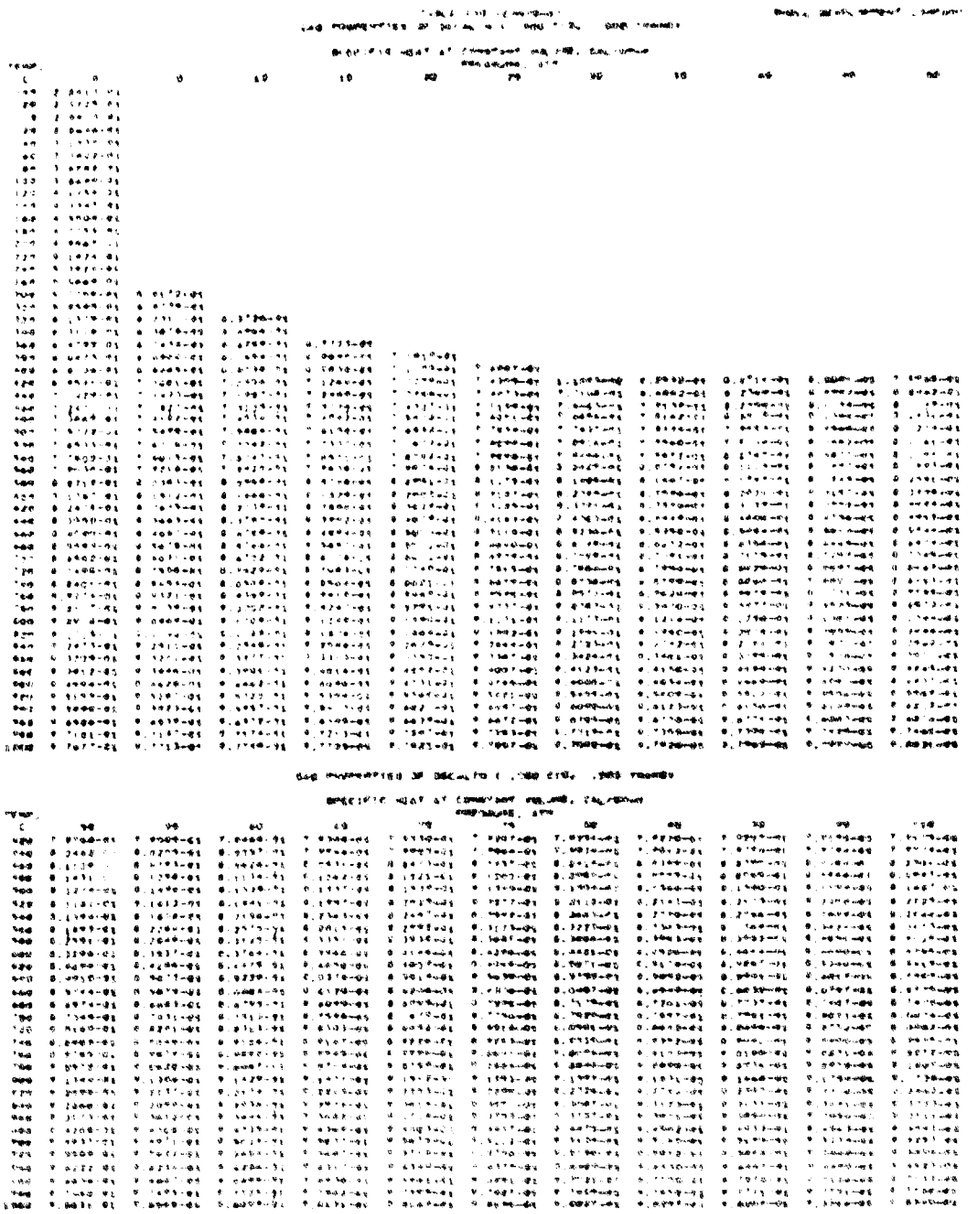
ENTHALPY, CAL/GM
PRESSURE, ATM

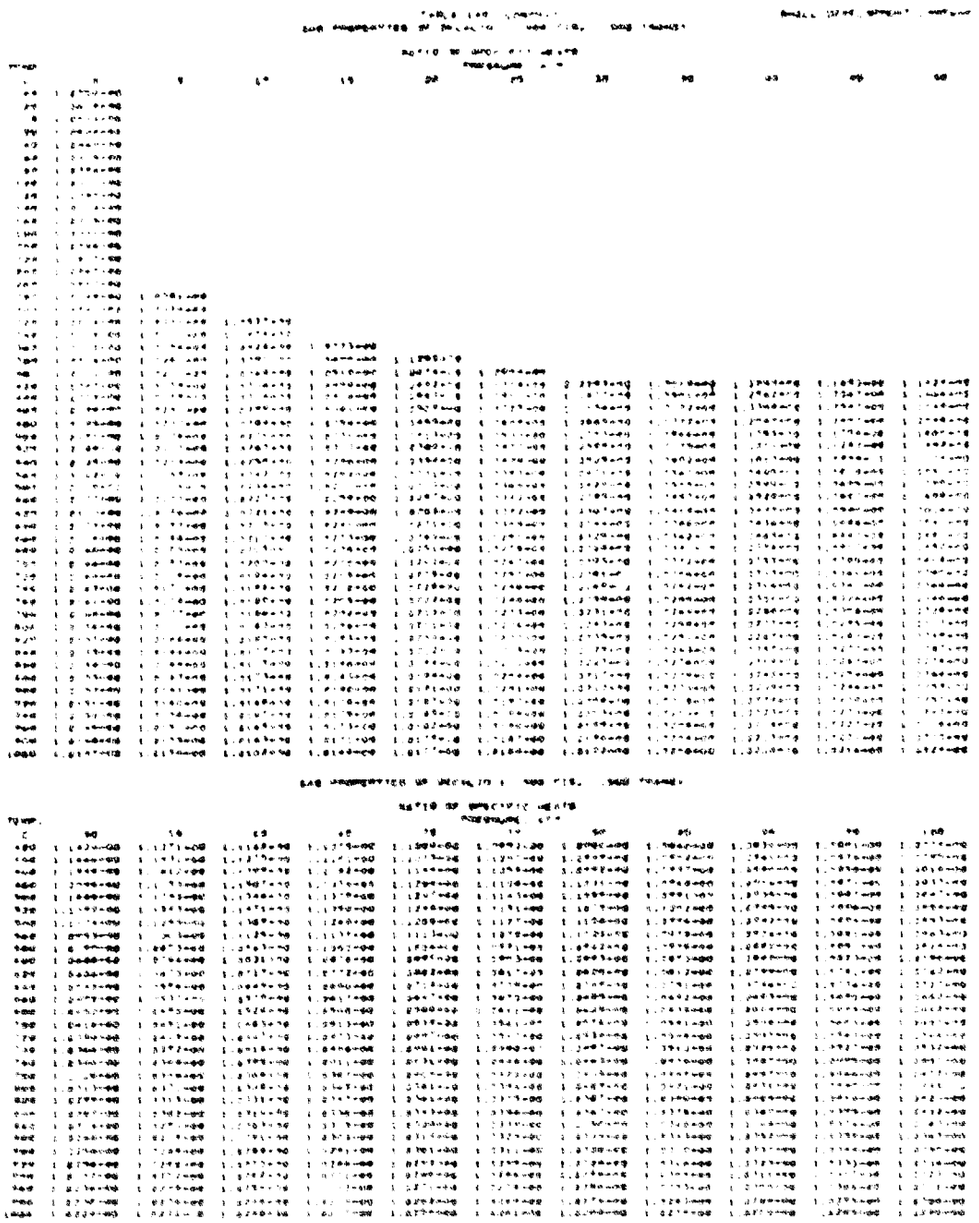
TEMP. K	20	25	30	40	50	60	70	80	90	100
420	2.9838E+02	2.9914E+02	2.9990E+02	3.0142E+02	3.0295E+02	3.0447E+02	3.0599E+02	3.0751E+02	3.0903E+02	3.1055E+02
440	2.7681E+02	2.7758E+02	2.7834E+02	2.7987E+02	2.8140E+02	2.8293E+02	2.8446E+02	2.8599E+02	2.8752E+02	2.8905E+02
460	2.9969E+02	2.9635E+02	2.9711E+02	2.9864E+02	3.0017E+02	3.0170E+02	3.0323E+02	3.0476E+02	3.0629E+02	3.0782E+02
480	3.1554E+02	3.1330E+02	3.1176E+02	3.1029E+02	3.0971E+02	3.0990E+02	3.1063E+02	3.1216E+02	3.1369E+02	3.1522E+02
500	3.3511E+02	3.3284E+02	3.3091E+02	3.2907E+02	3.2778E+02	3.2759E+02	3.2818E+02	3.2961E+02	3.3114E+02	3.3267E+02
520	3.5436E+02	3.5145E+02	3.4937E+02	3.4677E+02	3.4537E+02	3.4453E+02	3.4466E+02	3.4585E+02	3.4727E+02	3.4880E+02
540	3.7298E+02	3.7015E+02	3.6801E+02	3.6479E+02	3.6236E+02	3.6077E+02	3.6054E+02	3.6124E+02	3.6272E+02	3.6425E+02
560	3.9059E+02	3.8843E+02	3.8644E+02	3.8477E+02	3.8231E+02	3.8007E+02	3.7936E+02	3.7967E+02	3.8078E+02	3.8226E+02
580	4.0861E+02	4.0695E+02	4.0478E+02	4.0317E+02	4.0048E+02	3.9788E+02	3.9677E+02	3.9717E+02	3.9822E+02	3.9966E+02
600	4.2629E+02	4.2496E+02	4.2298E+02	4.2114E+02	4.1852E+02	4.1594E+02	4.1465E+02	4.1483E+02	4.1571E+02	4.1709E+02
620	4.4400E+02	4.4254E+02	4.4107E+02	4.3907E+02	4.3642E+02	4.3374E+02	4.3218E+02	4.3207E+02	4.3284E+02	4.3421E+02
640	4.6161E+02	4.6059E+02	4.5927E+02	4.5778E+02	4.5476E+02	4.5211E+02	4.5041E+02	4.4986E+02	4.5041E+02	4.5174E+02
660	4.7909E+02	4.7861E+02	4.7736E+02	4.7621E+02	4.7367E+02	4.7140E+02	4.7008E+02	4.6917E+02	4.6956E+02	4.7082E+02
680	4.9709E+02	4.9675E+02	4.9568E+02	4.9463E+02	4.9264E+02	4.9058E+02	4.8937E+02	4.8810E+02	4.8831E+02	4.8950E+02
700	5.1504E+02	5.1497E+02	5.1395E+02	5.1291E+02	5.1119E+02	5.1105E+02	5.1... E+02	5.0909E+02	5.0863E+02	5.0973E+02
720	5.3430E+02	5.3331E+02	5.3233E+02	5.3137E+02	5.3066E+02	5.2997E+02	5.2879E+02	5.2772E+02	5.2693E+02	5.2796E+02
740	5.5268E+02	5.5175E+02	5.5083E+02	5.4994E+02	5.4907E+02	5.4824E+02	5.4704E+02	5.4597E+02	5.4518E+02	5.4493E+02
760	5.7129E+02	5.7032E+02	5.6965E+02	5.6861E+02	5.6779E+02	5.6700E+02	5.6625E+02	5.6504E+02	5.6408E+02	5.6352E+02
780	5.8998E+02	5.8901E+02	5.8815E+02	5.8745E+02	5.8663E+02	5.8587E+02	5.8511E+02	5.8343E+02	5.8231E+02	5.8206E+02
800	6.0868E+02	6.0781E+02	6.0706E+02	6.0630E+02	6.0565E+02	6.0481E+02	6.0417E+02	6.0290E+02	6.0170E+02	6.0115E+02
820	6.2751E+02	6.2676E+02	6.2604E+02	6.2532E+02	6.2463E+02	6.2395E+02	6.2328E+02	6.2217E+02	6.2121E+02	6.2059E+02
840	6.4657E+02	6.4585E+02	6.4515E+02	6.4447E+02	6.4380E+02	6.4316E+02	6.4254E+02	6.4144E+02	6.4037E+02	6.4000E+02
860	6.6575E+02	6.6505E+02	6.6438E+02	6.6372E+02	6.6310E+02	6.6249E+02	6.6189E+02	6.6078E+02	6.5975E+02	6.5935E+02
880	6.8505E+02	6.8436E+02	6.8370E+02	6.8305E+02	6.8243E+02	6.8183E+02	6.8124E+02	6.8015E+02	6.7911E+02	6.7871E+02
900	7.0444E+02	7.0378E+02	7.0314E+02	7.0252E+02	7.0192E+02	7.0134E+02	7.0077E+02	6.9969E+02	6.9866E+02	6.9827E+02
920	7.2398E+02	7.2330E+02	7.2265E+02	7.2202E+02	7.2142E+02	7.2083E+02	7.2026E+02	7.1919E+02	7.1816E+02	7.1776E+02
940	7.4364E+02	7.4297E+02	7.4232E+02	7.4169E+02	7.4109E+02	7.4050E+02	7.3993E+02	7.3886E+02	7.3783E+02	7.3743E+02
960	7.6340E+02	7.6280E+02	7.6223E+02	7.6161E+02	7.6102E+02	7.6043E+02	7.5986E+02	7.5880E+02	7.5777E+02	7.5737E+02
980	7.8329E+02	7.8277E+02	7.8226E+02	7.8177E+02	7.8120E+02	7.8061E+02	7.8003E+02	7.7896E+02	7.7793E+02	7.7753E+02
1000	8.0321E+02	8.0276E+02	8.0230E+02	8.0183E+02	8.0137E+02	8.0093E+02	8.0048E+02	7.9941E+02	7.9838E+02	7.9798E+02

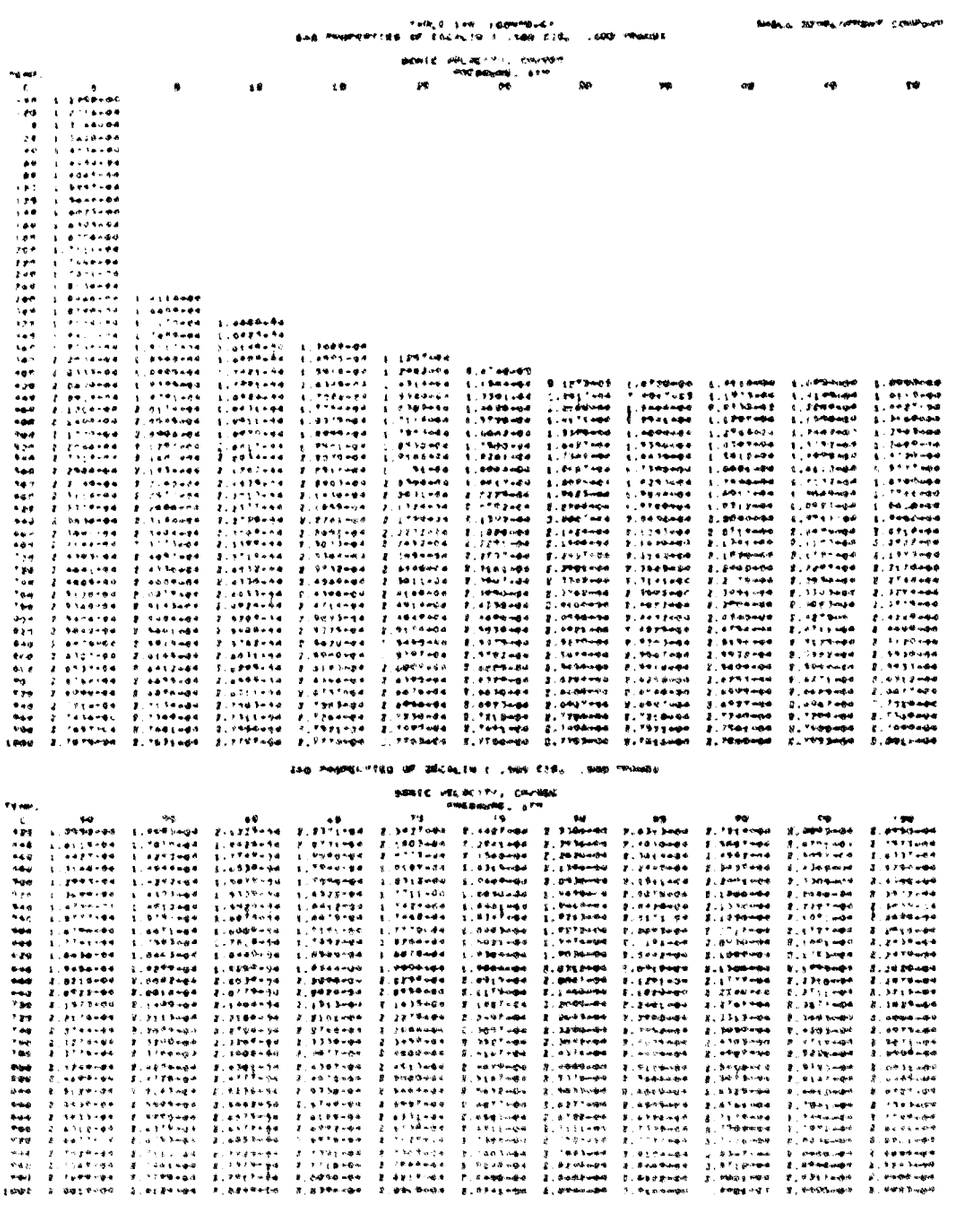


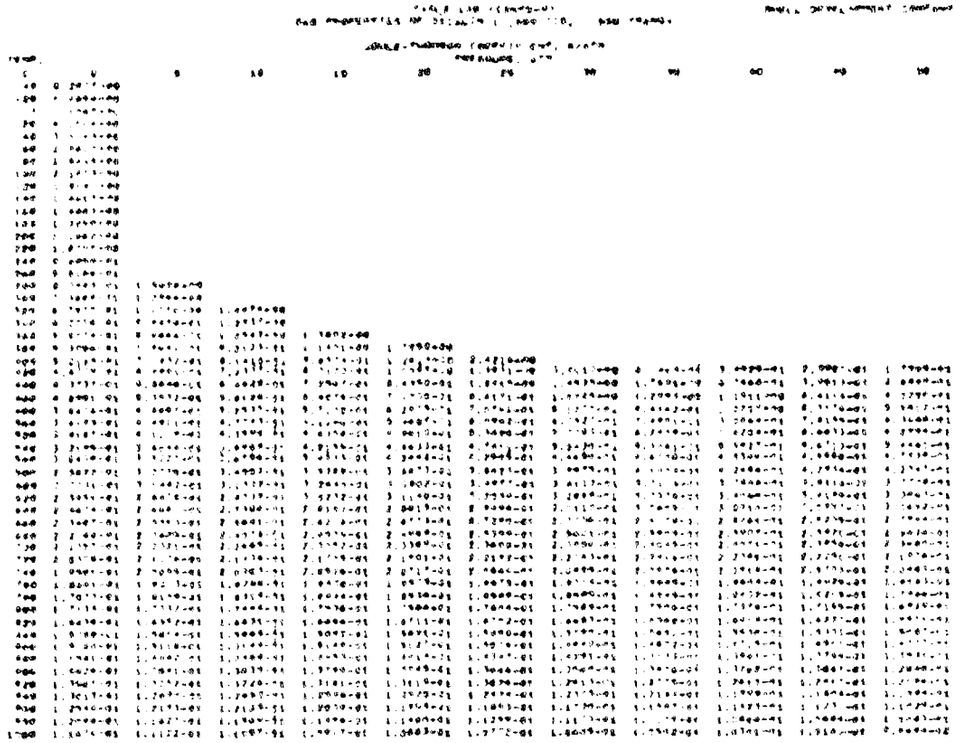


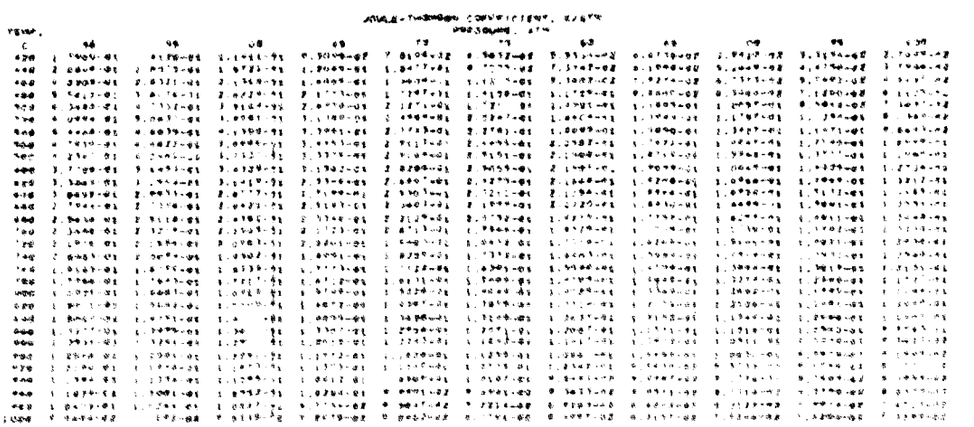


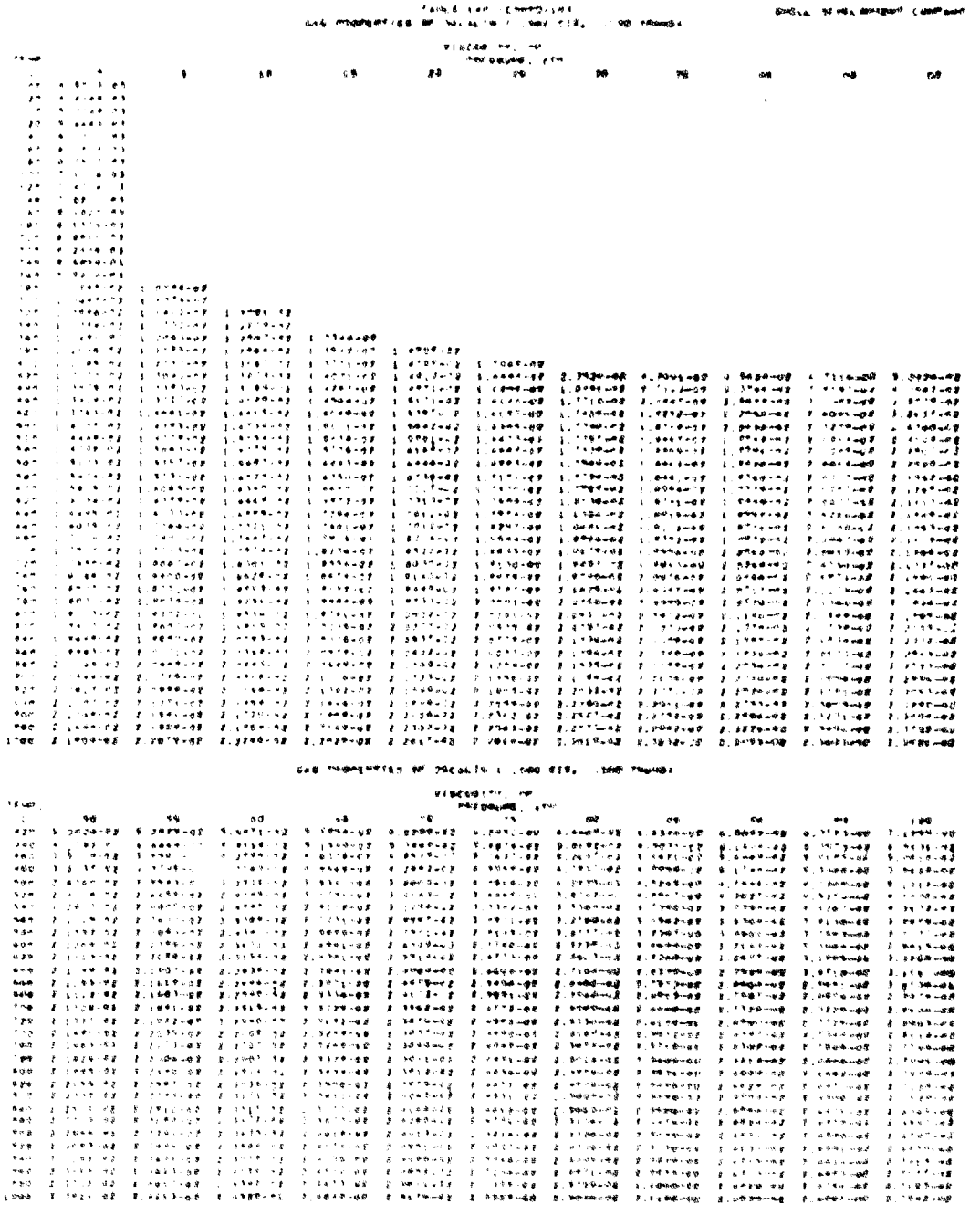


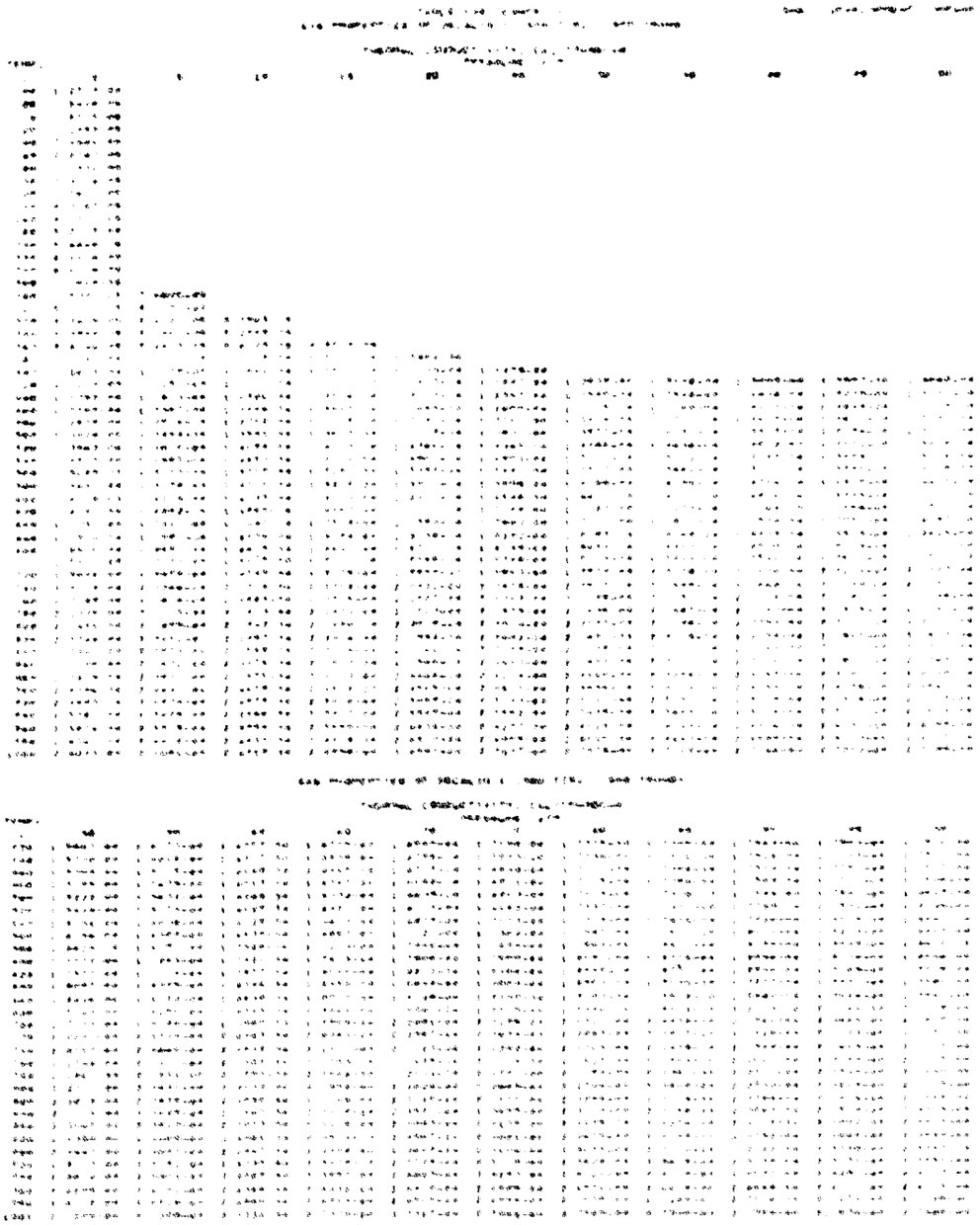


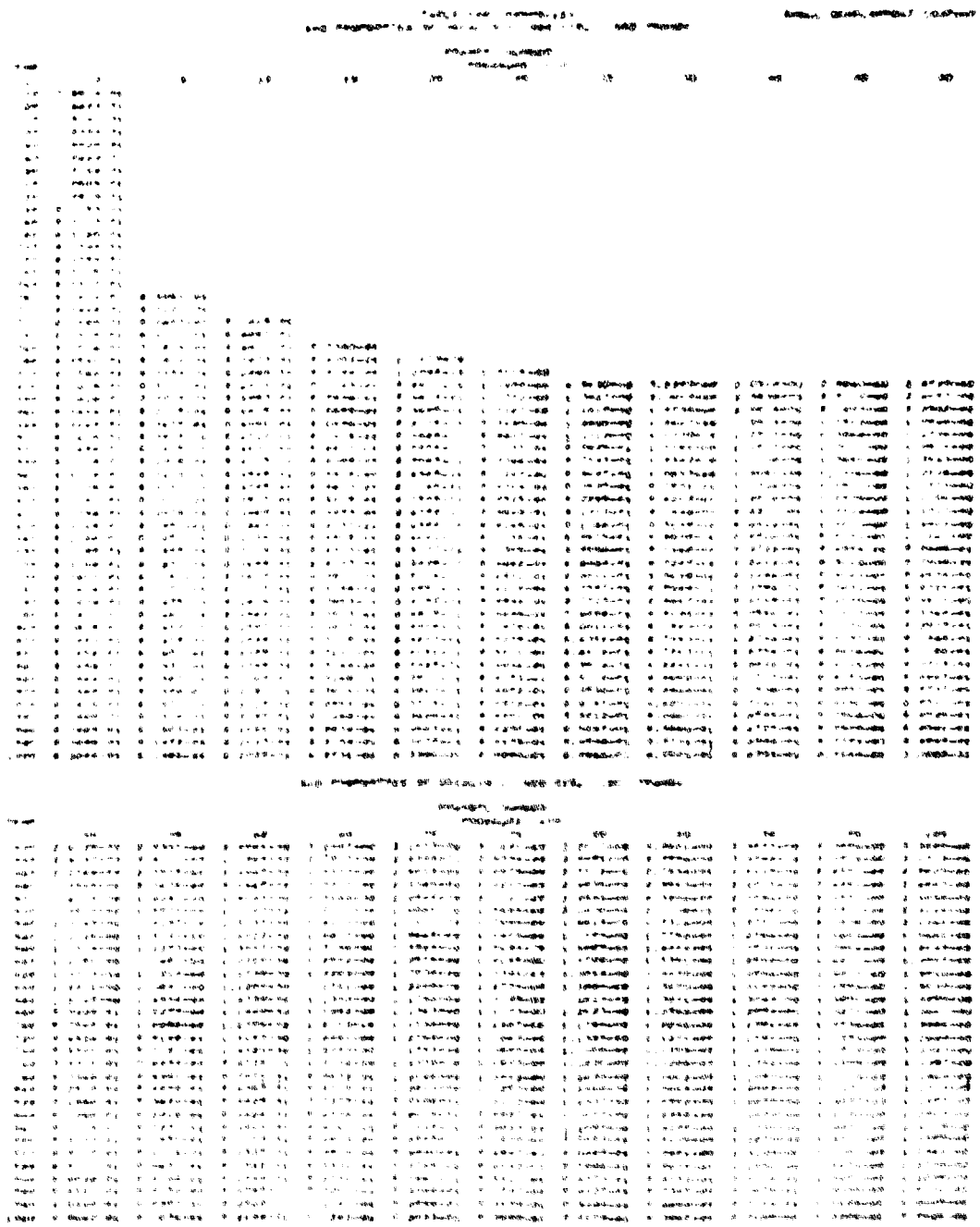


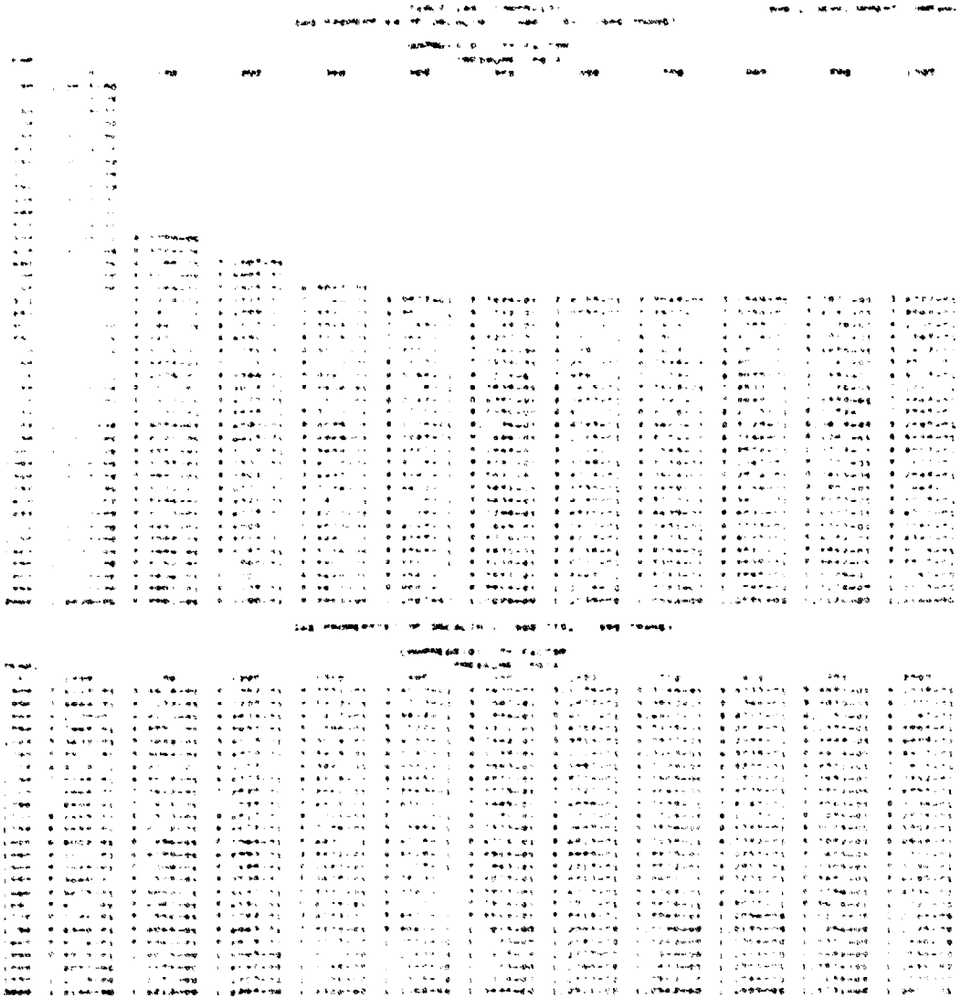


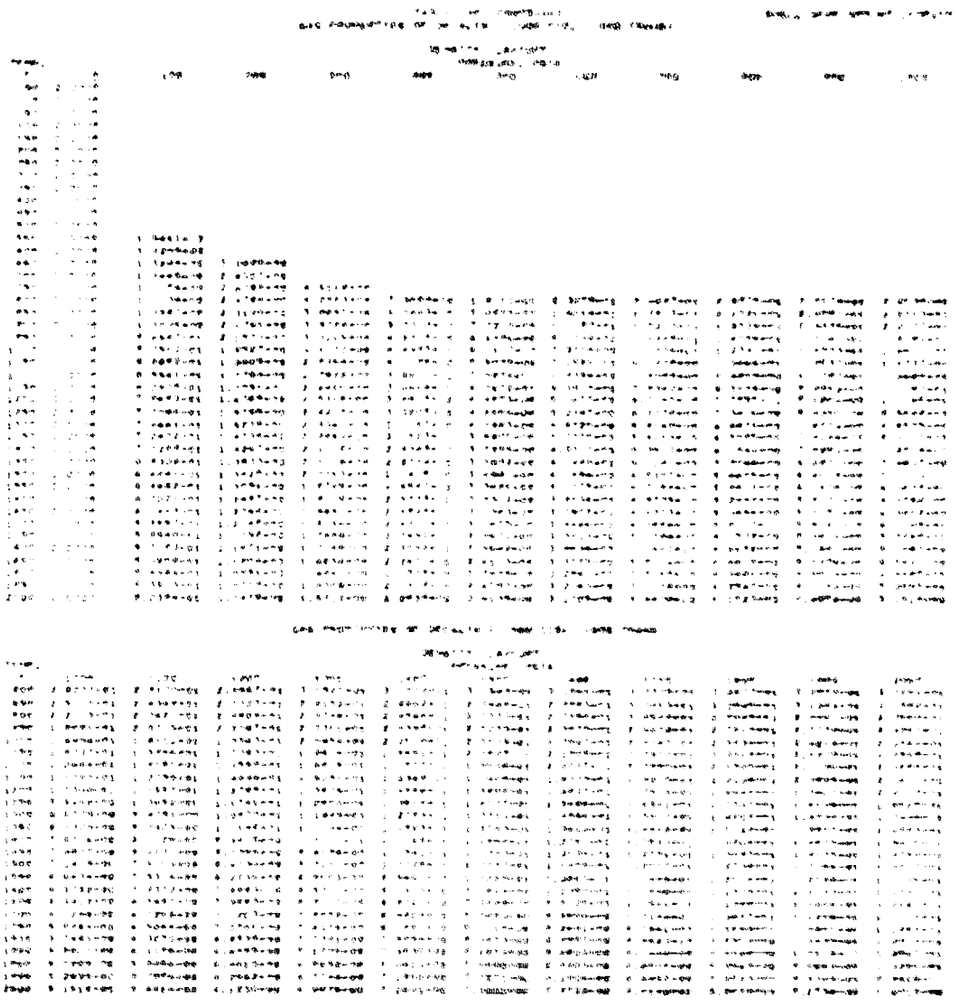


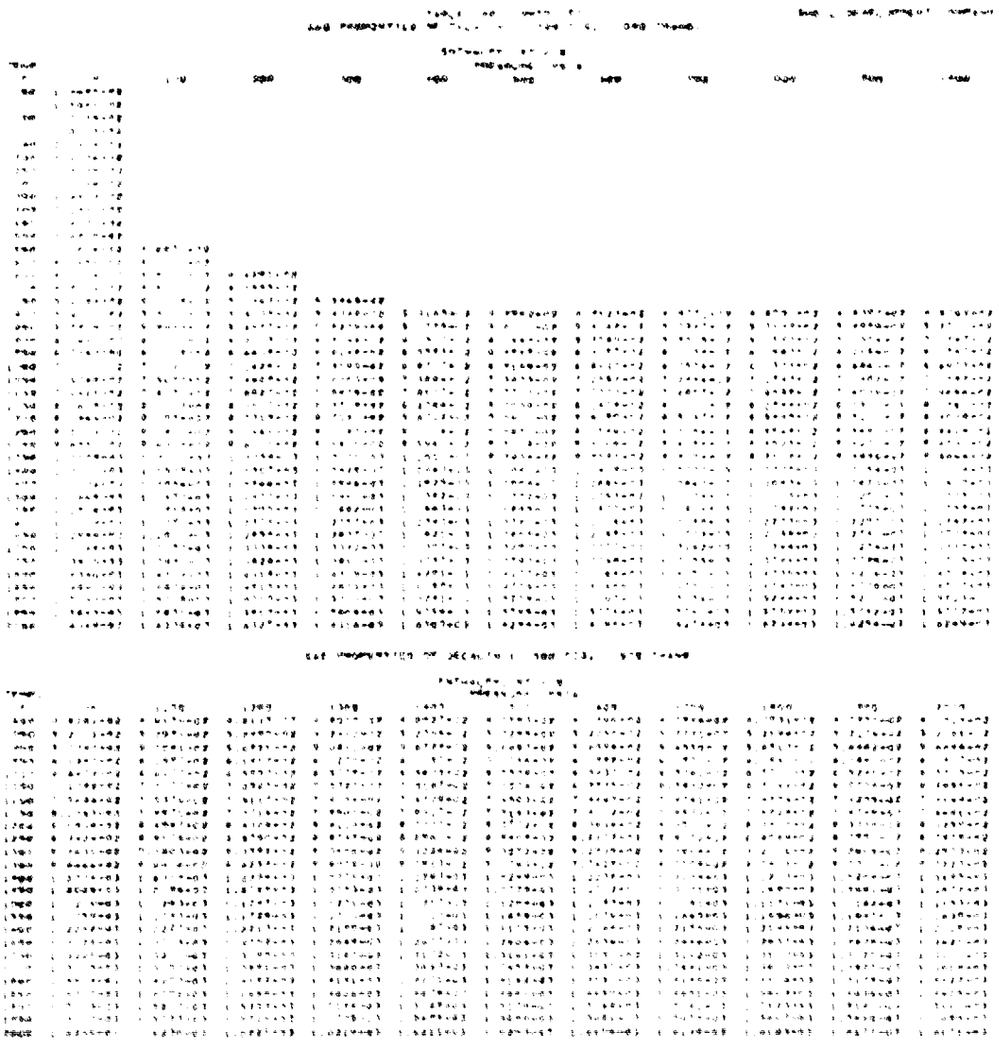


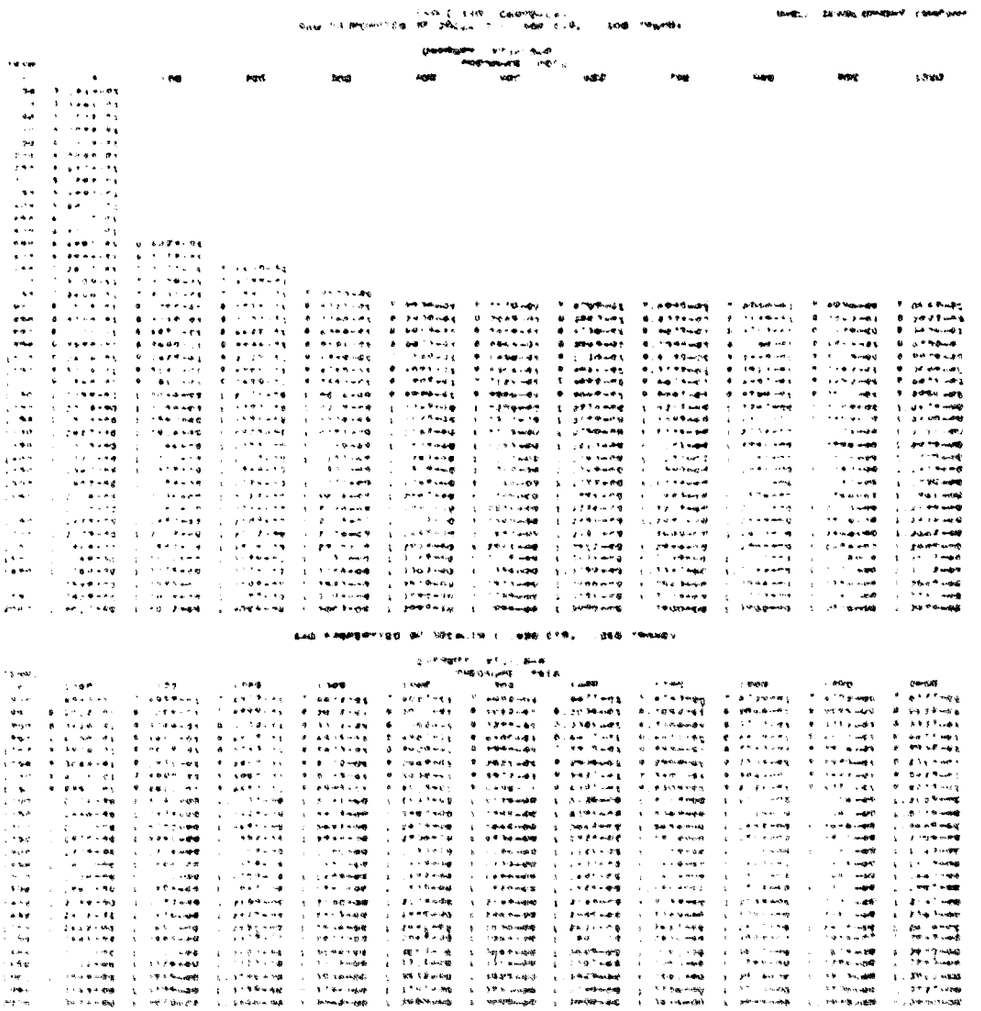


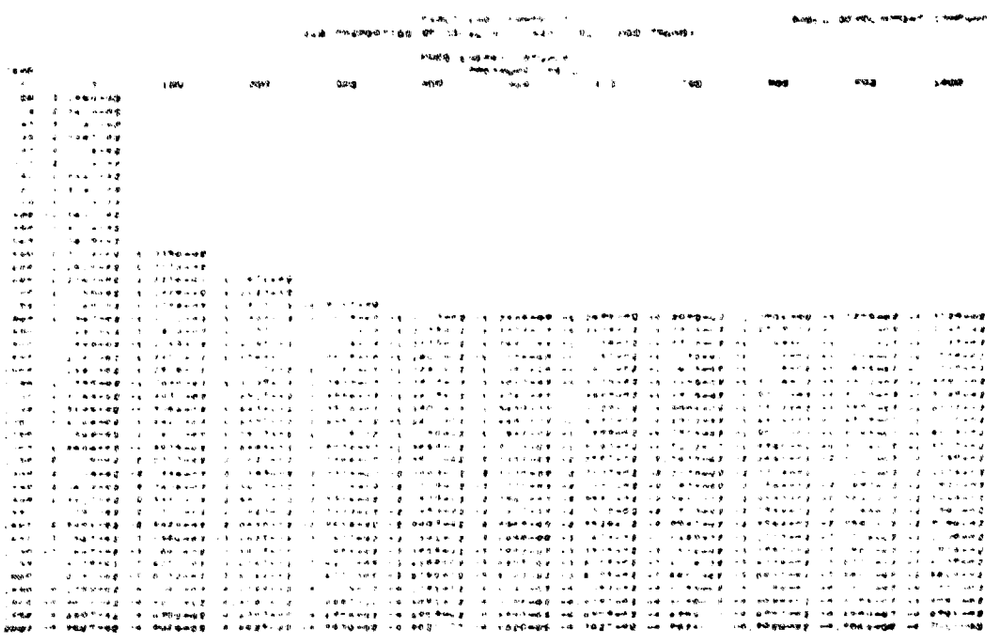


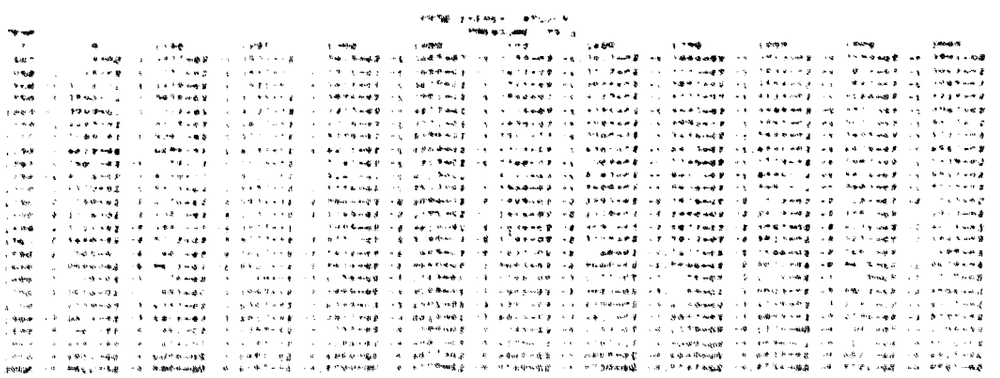


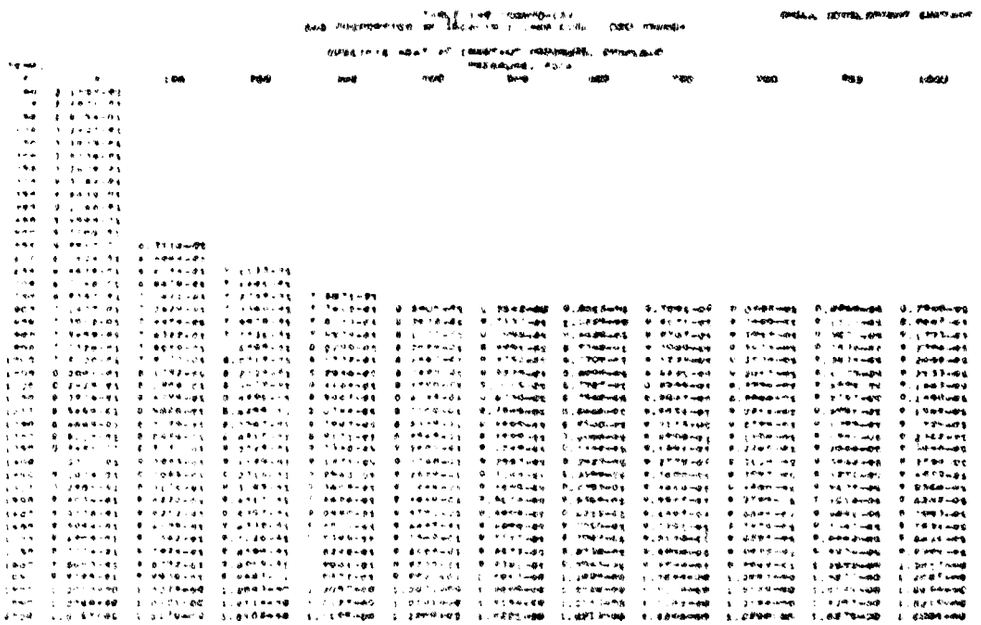


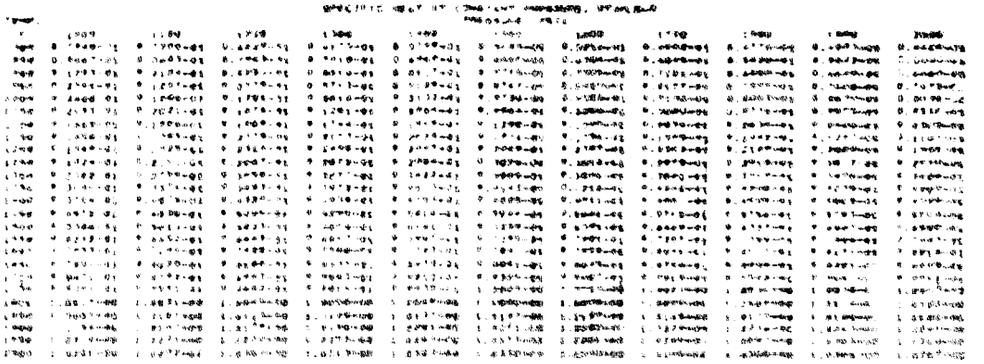


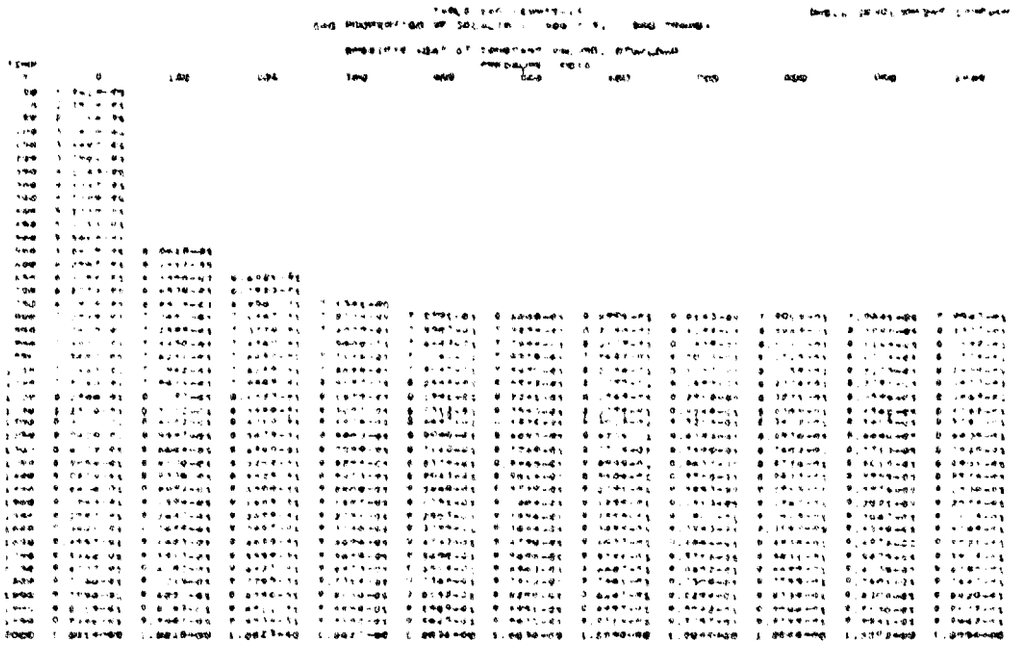


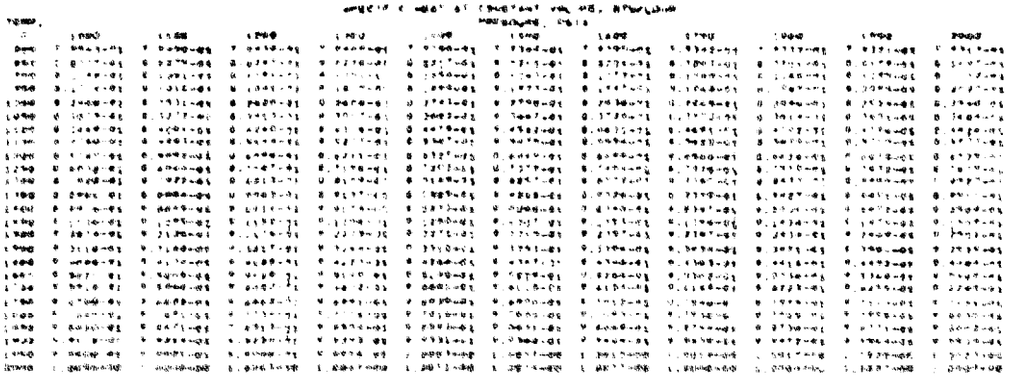


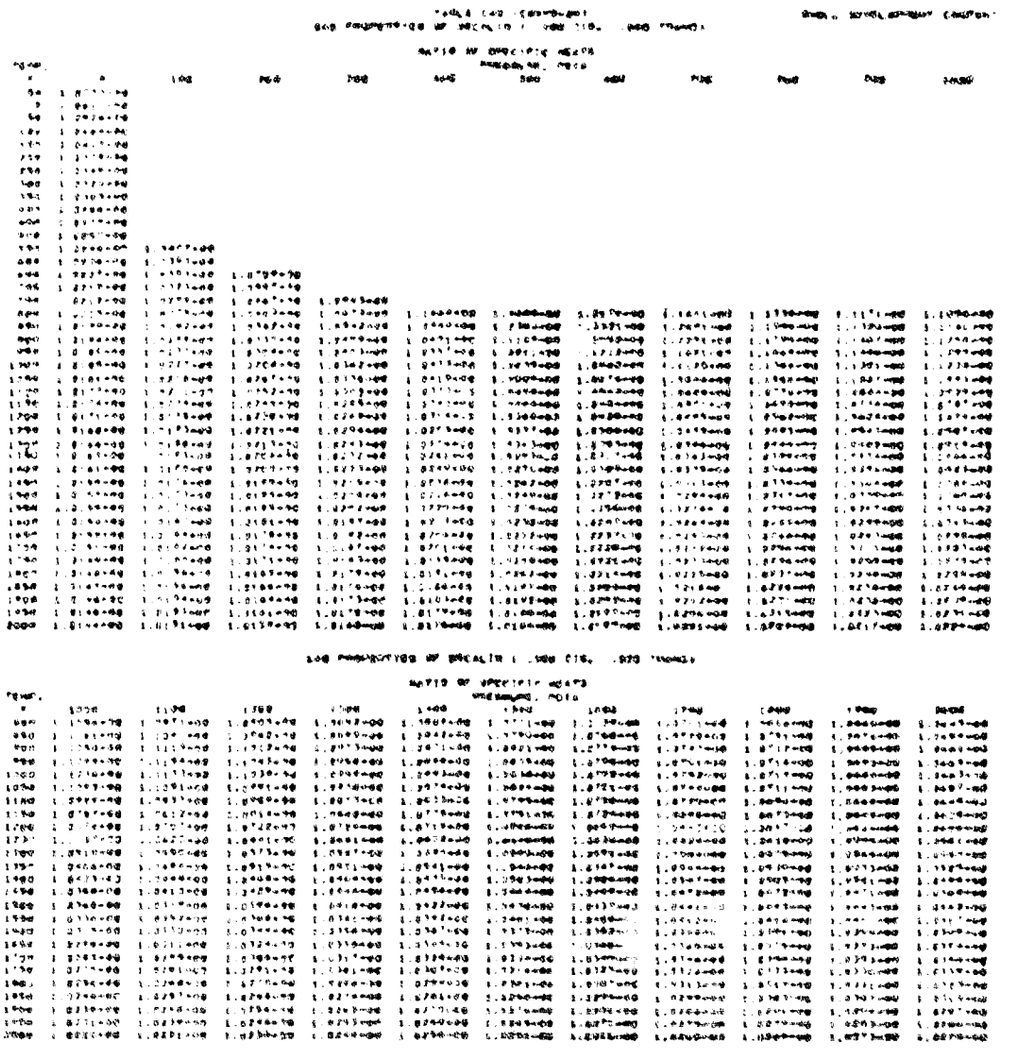


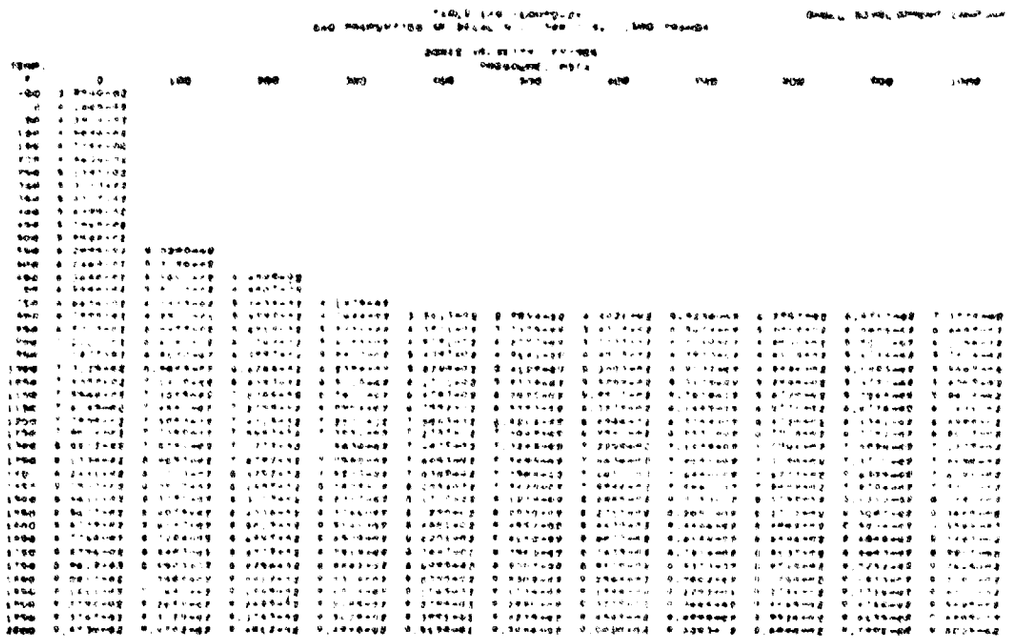


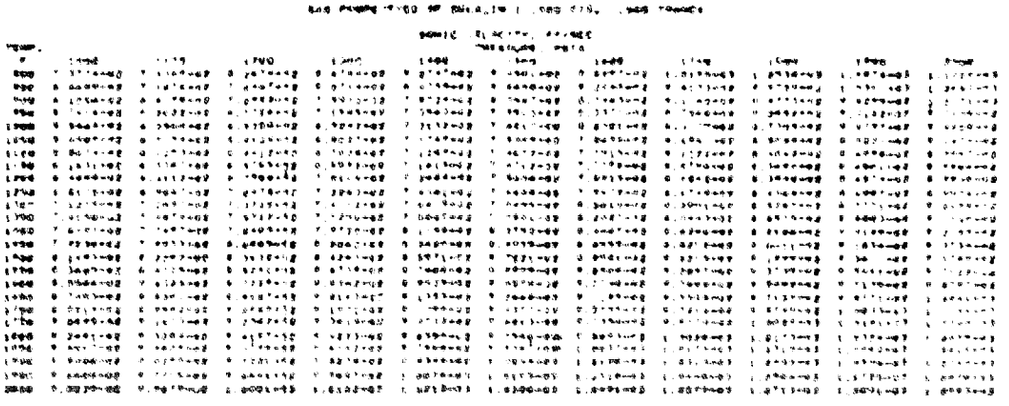


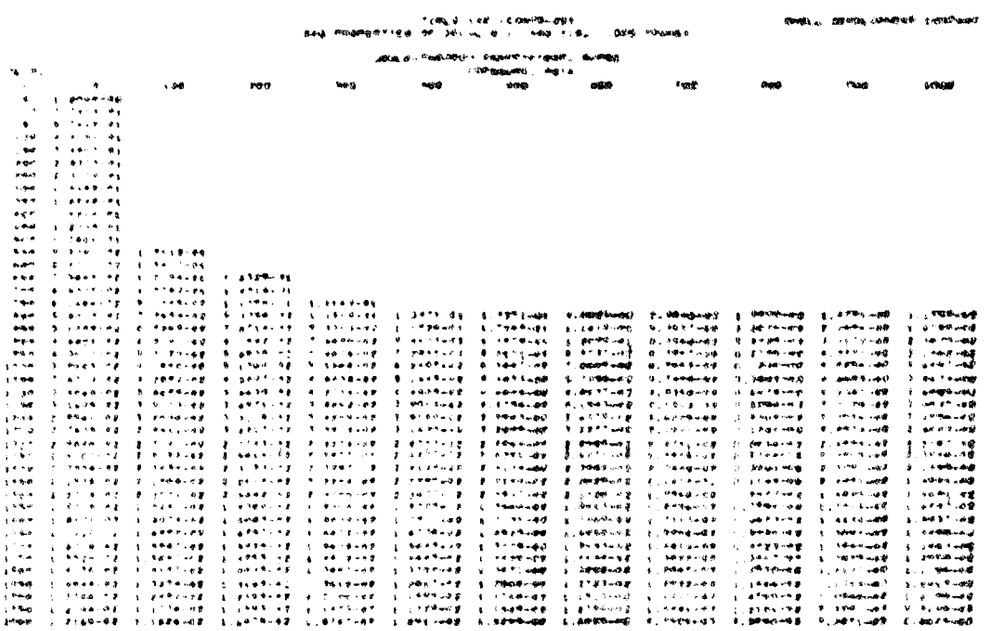


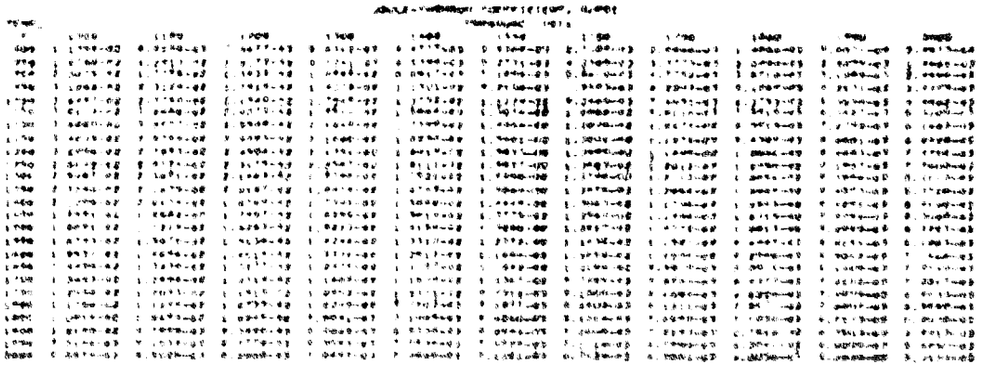


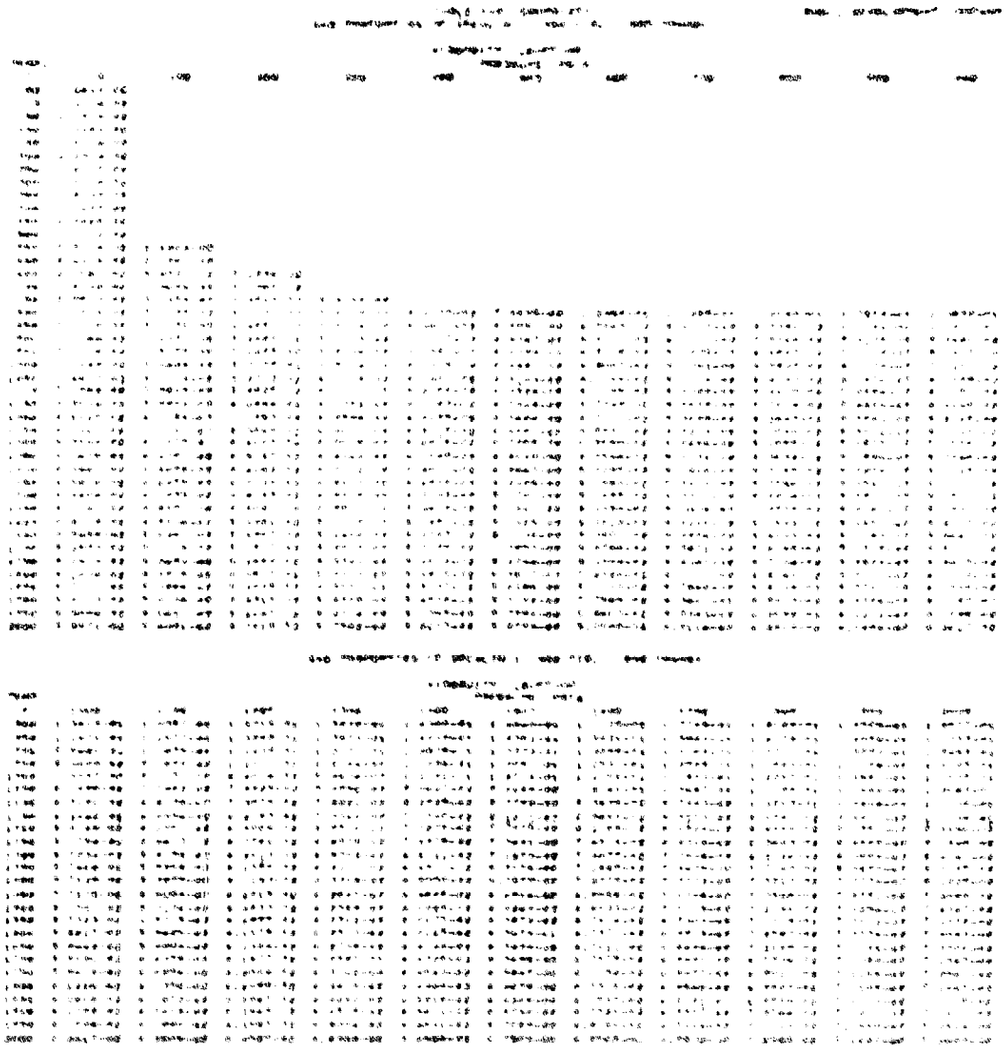


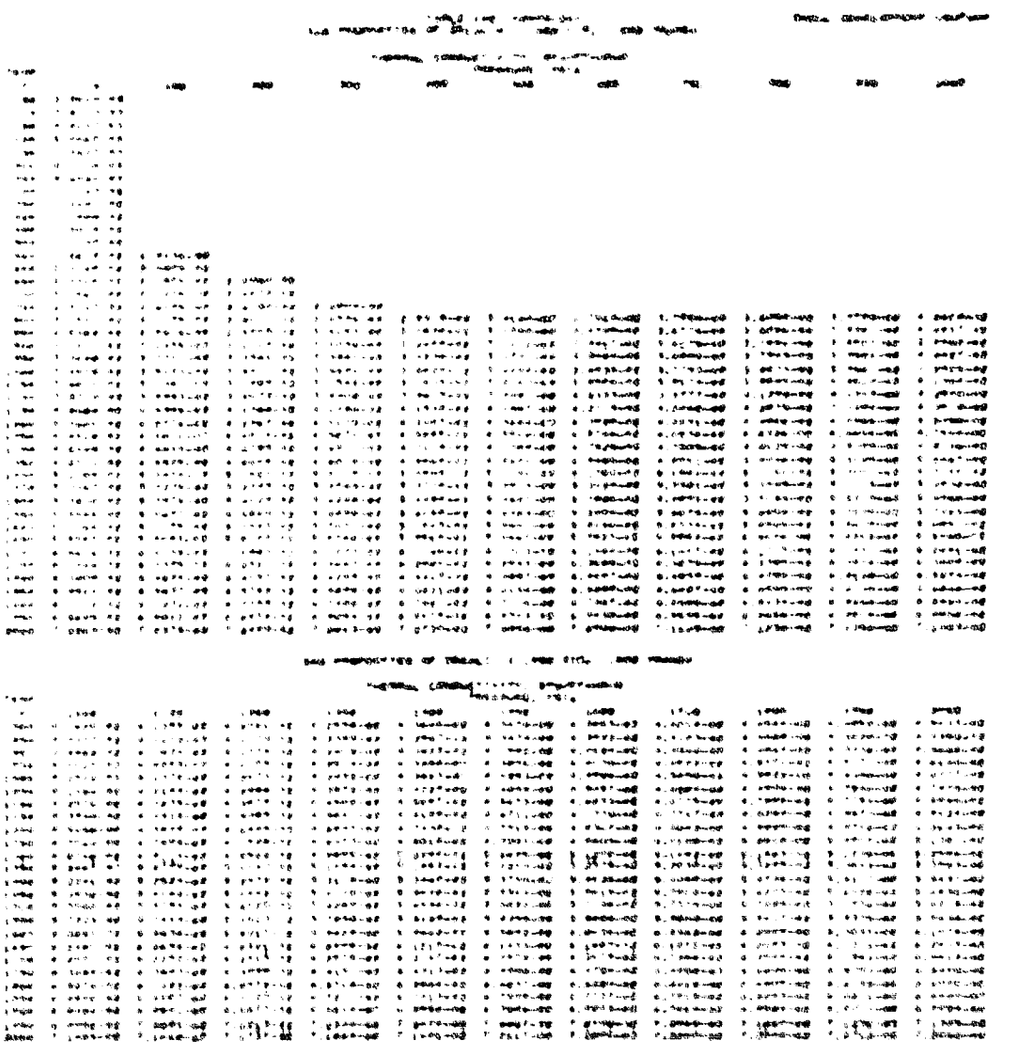












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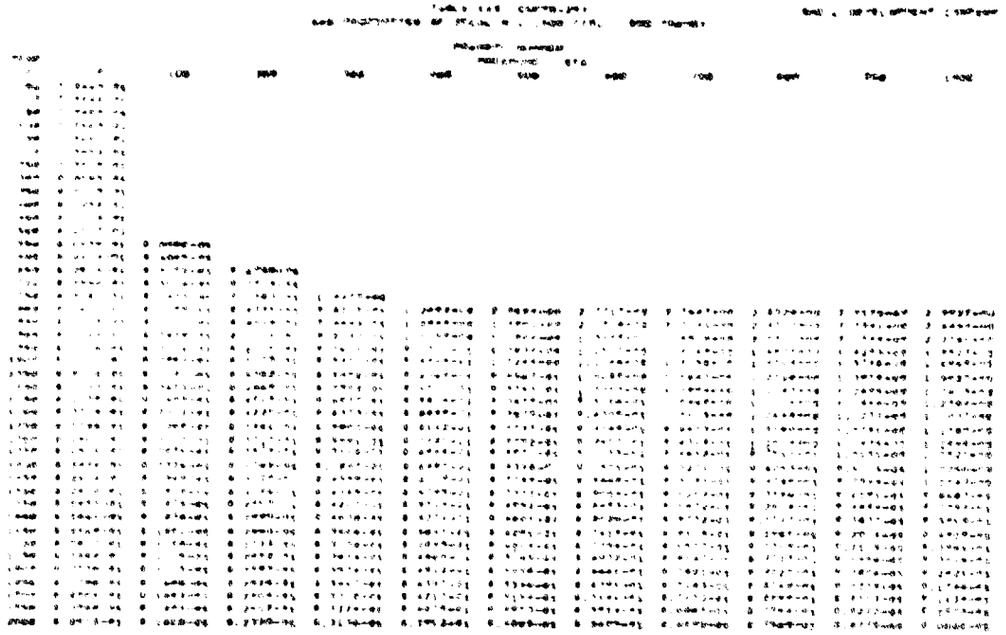
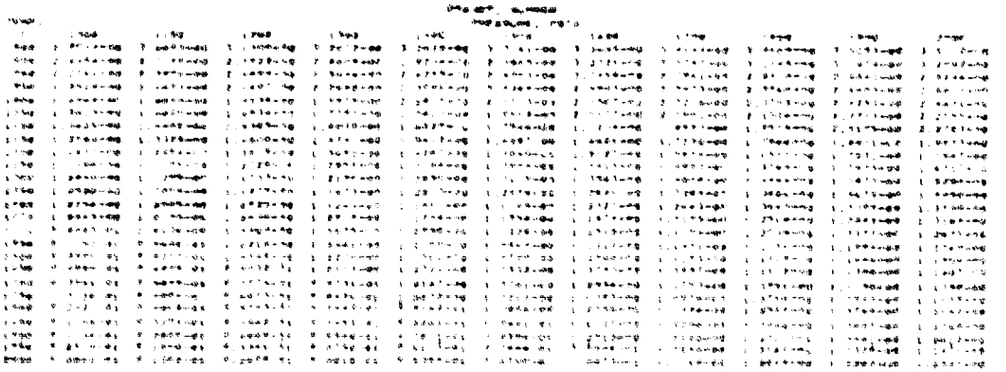
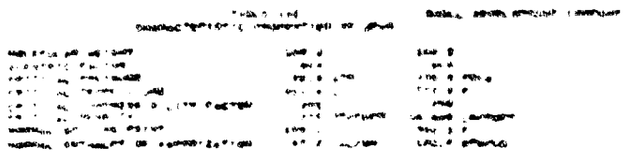
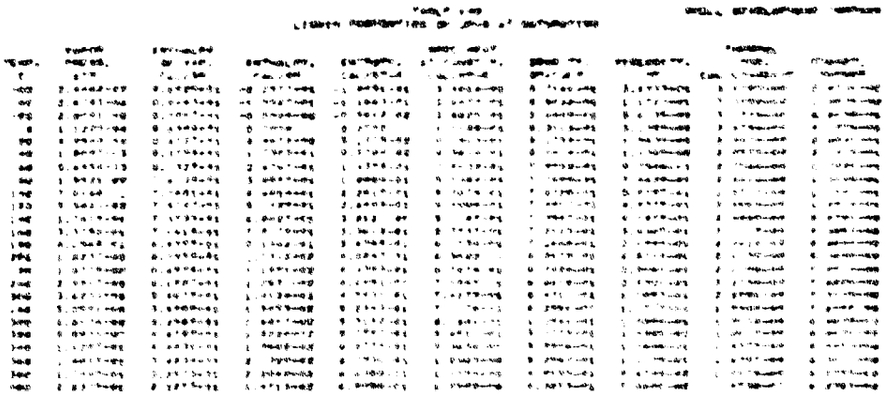
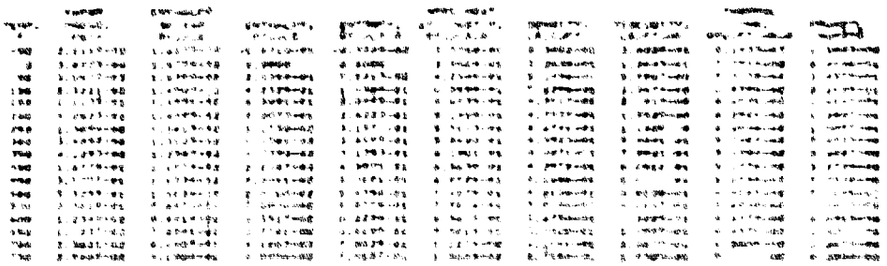
Part II

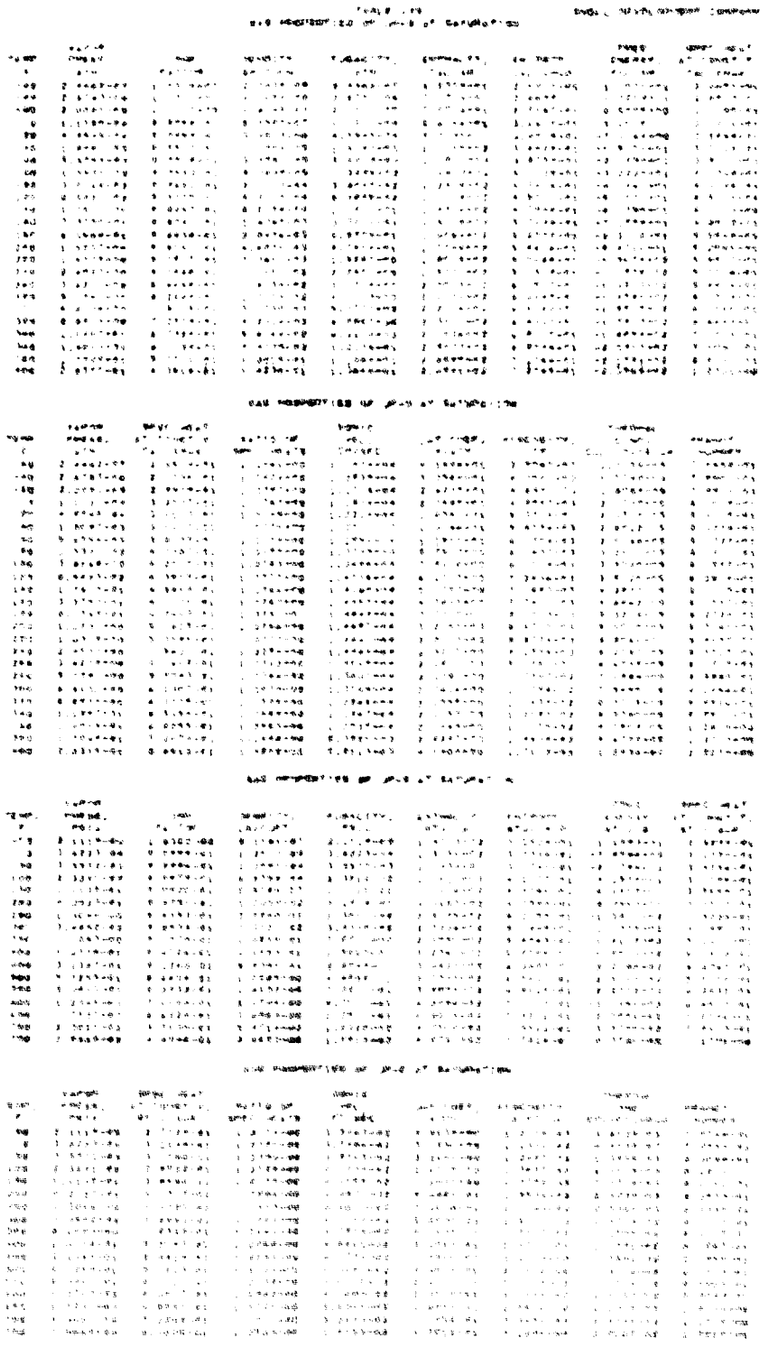


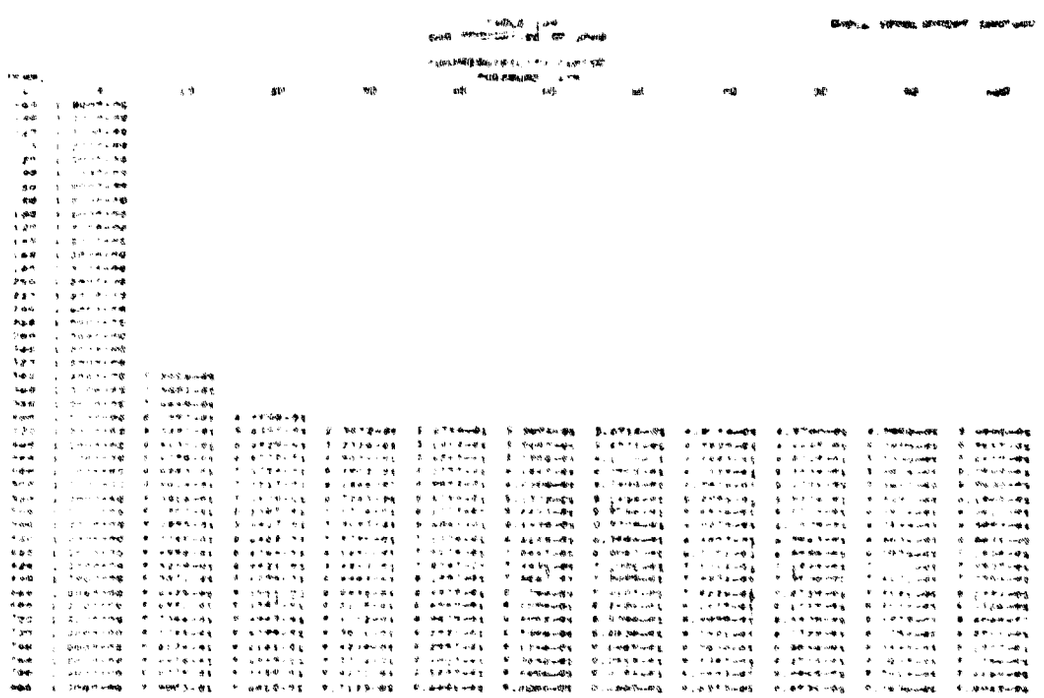


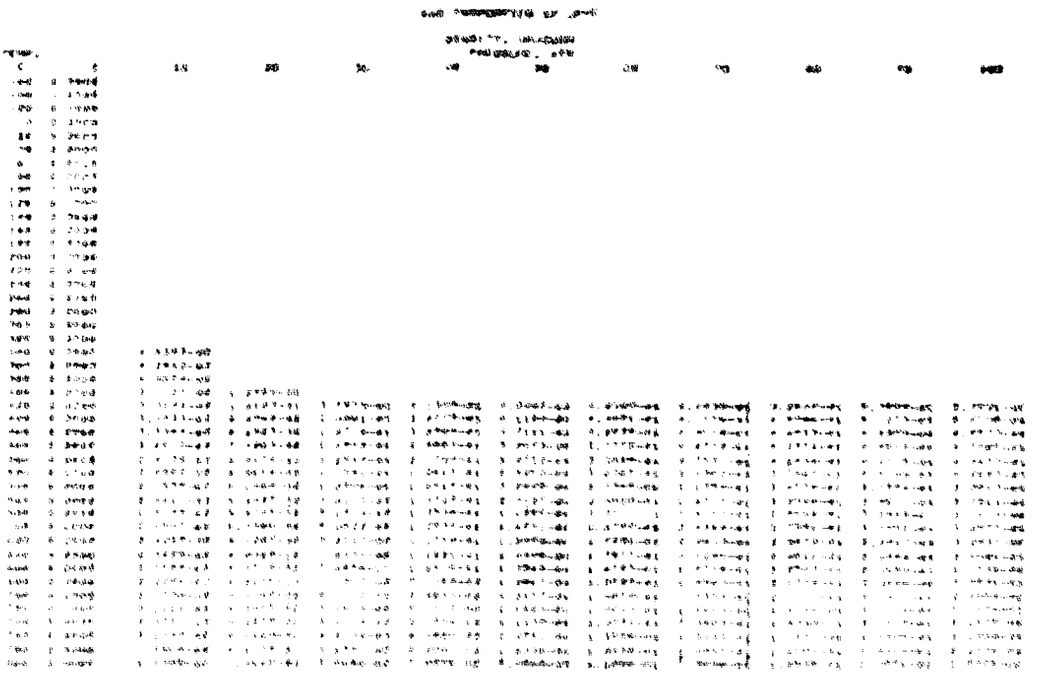


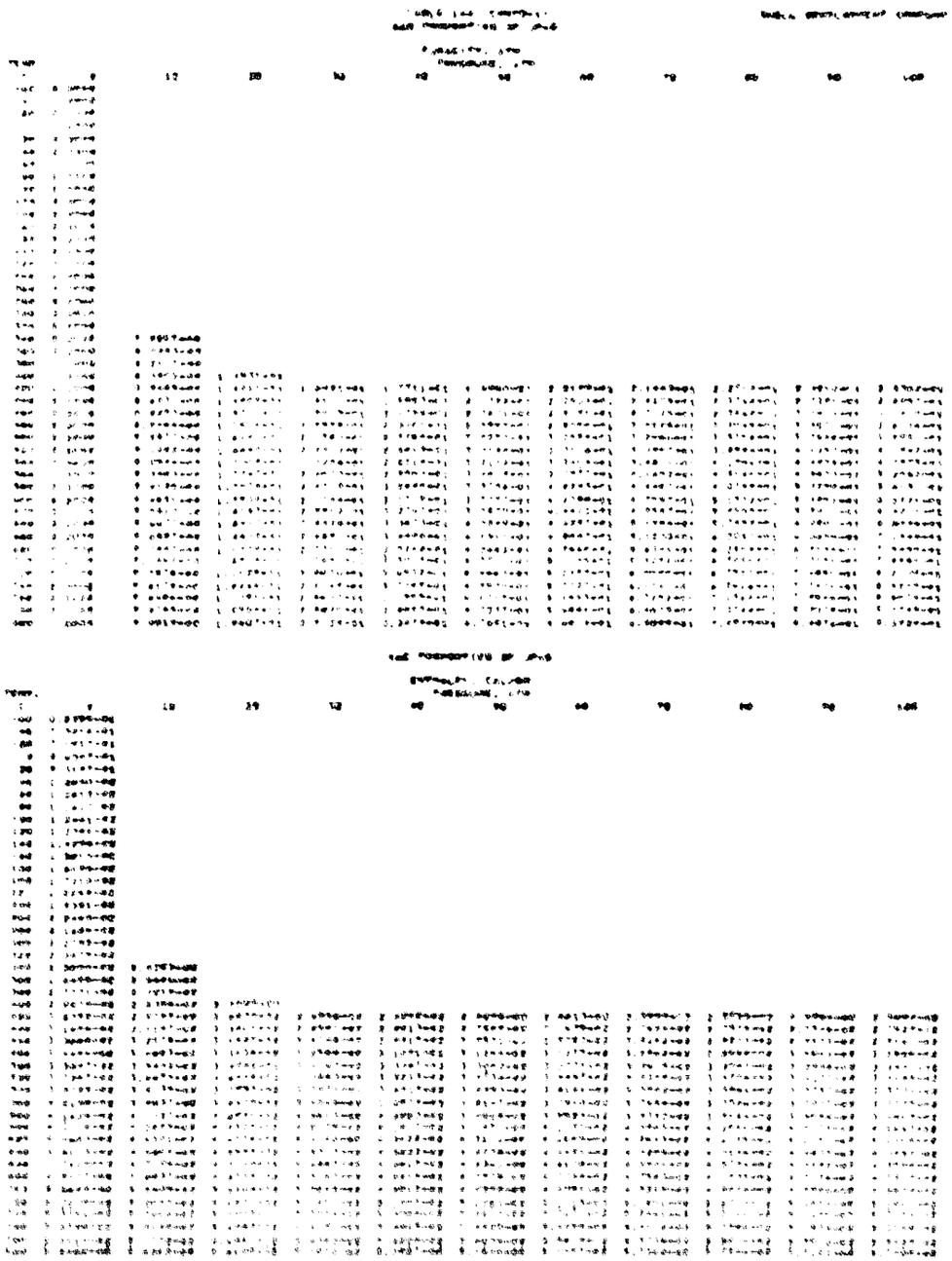


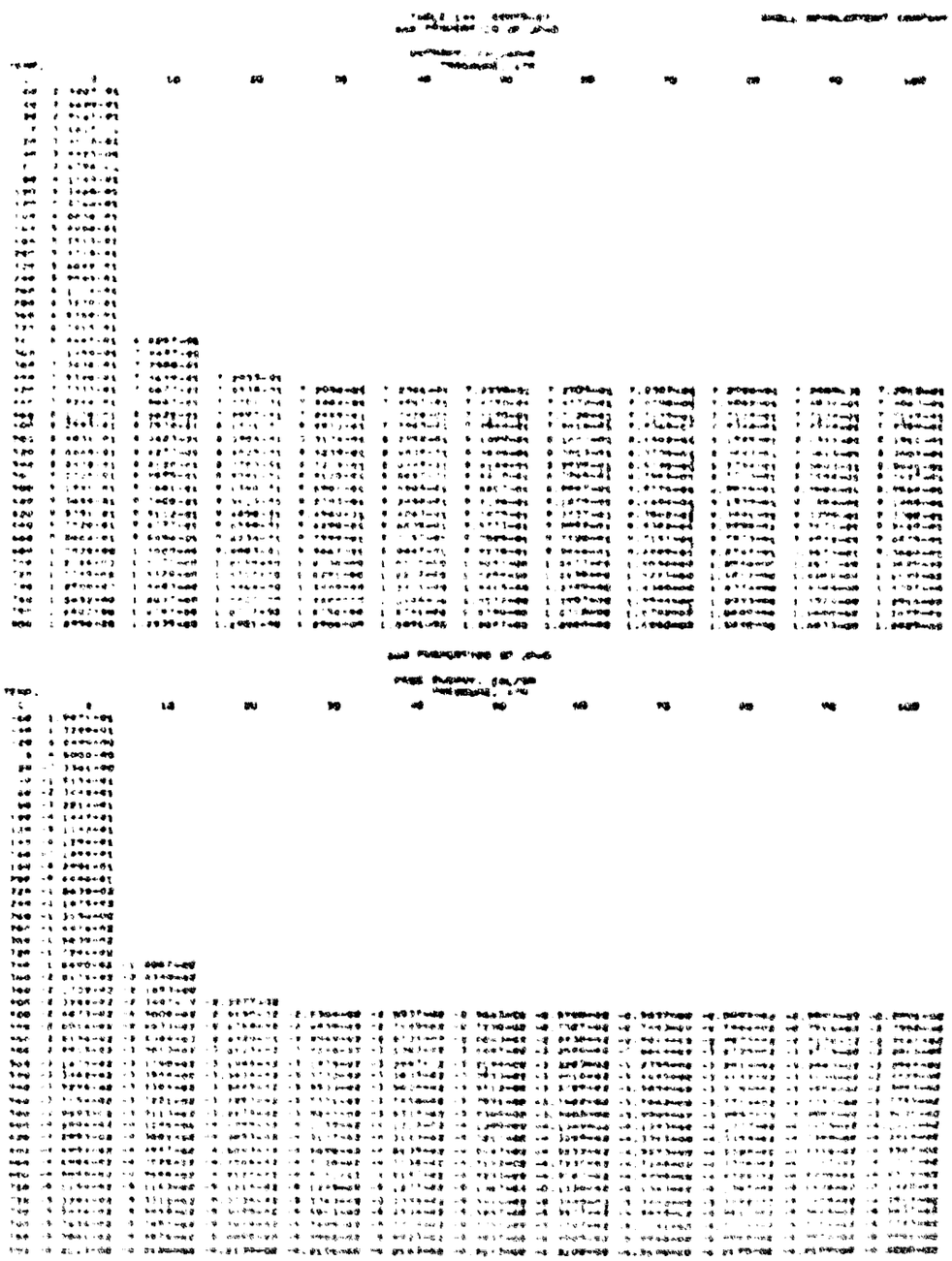


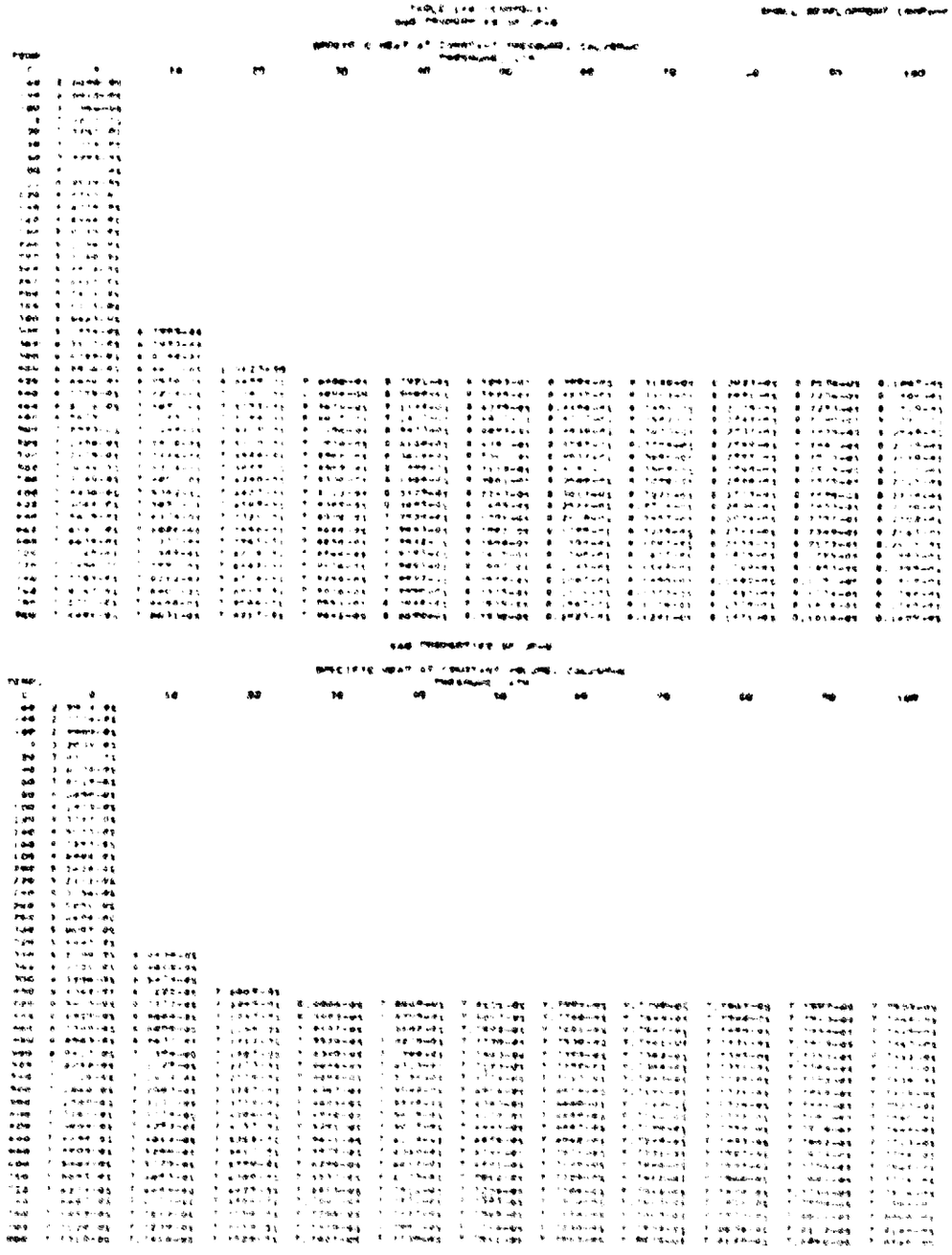


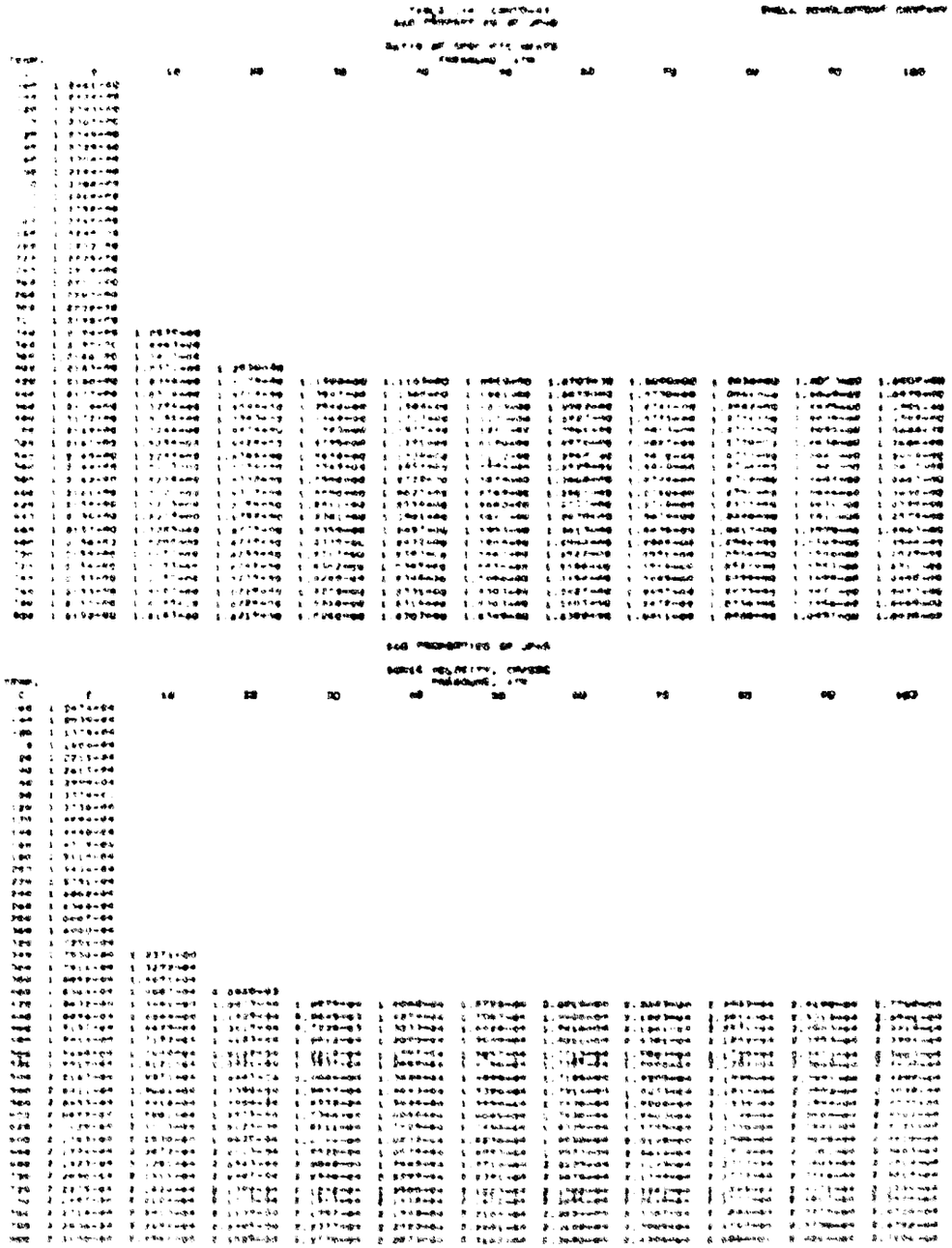


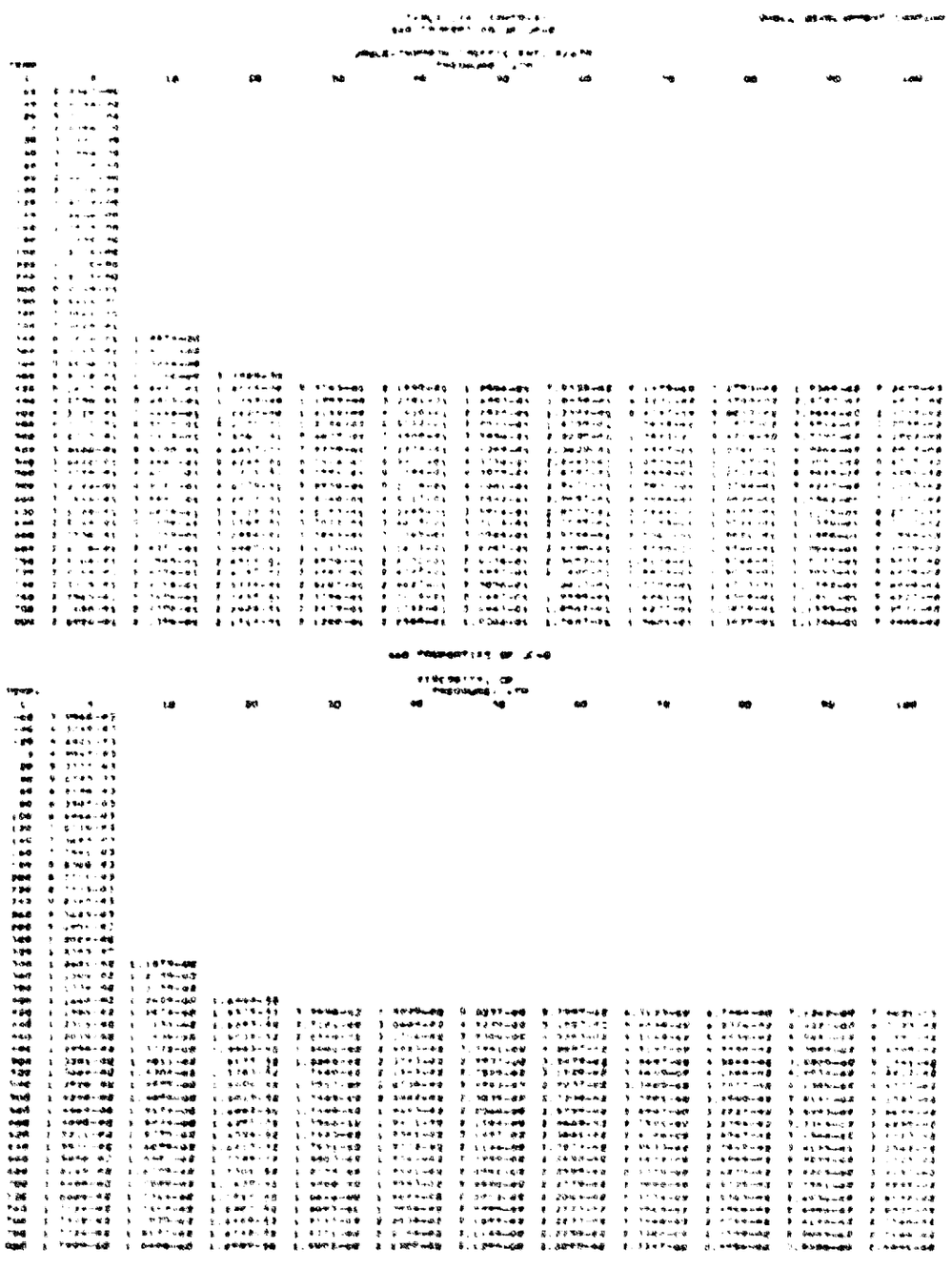


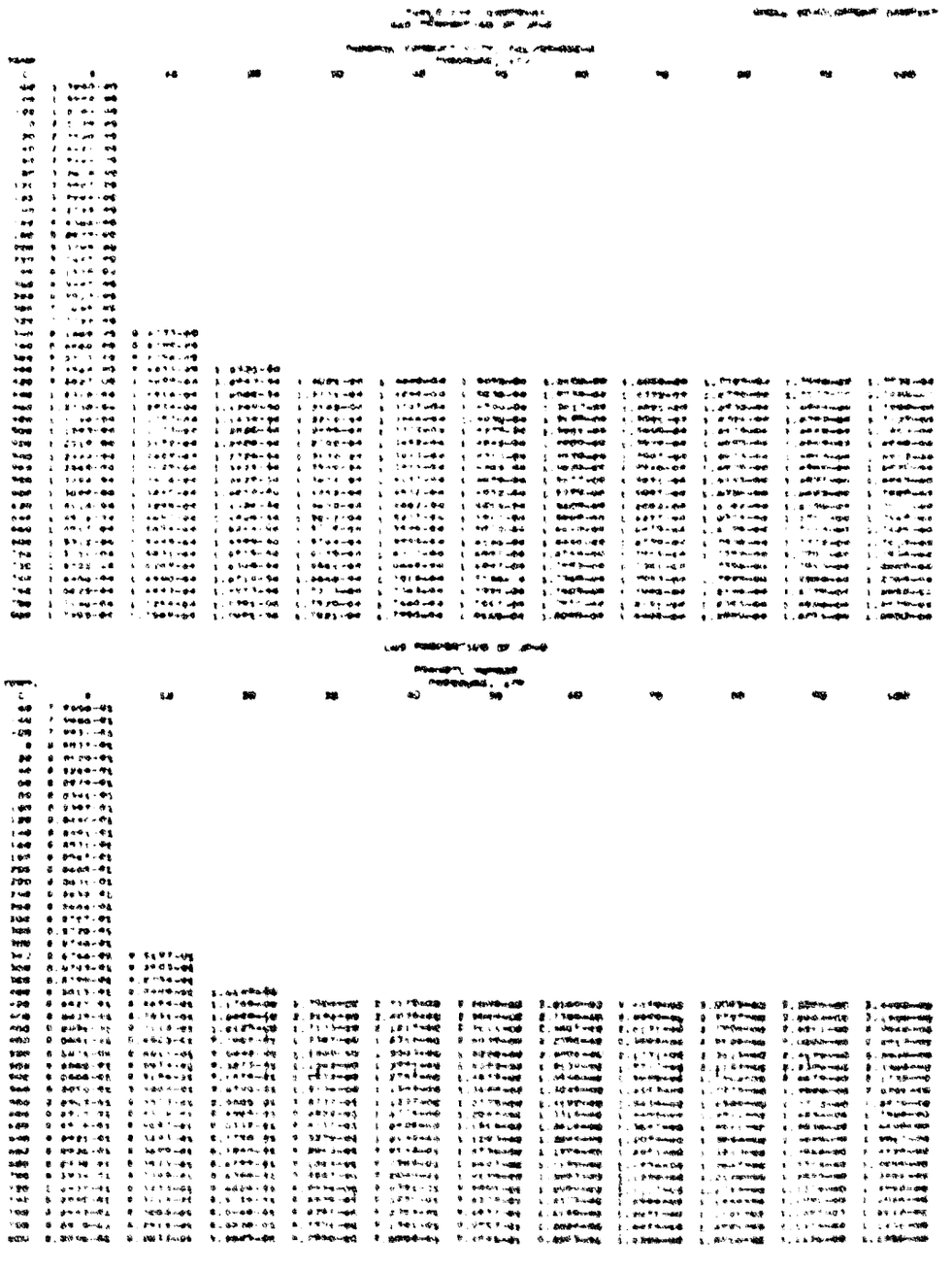


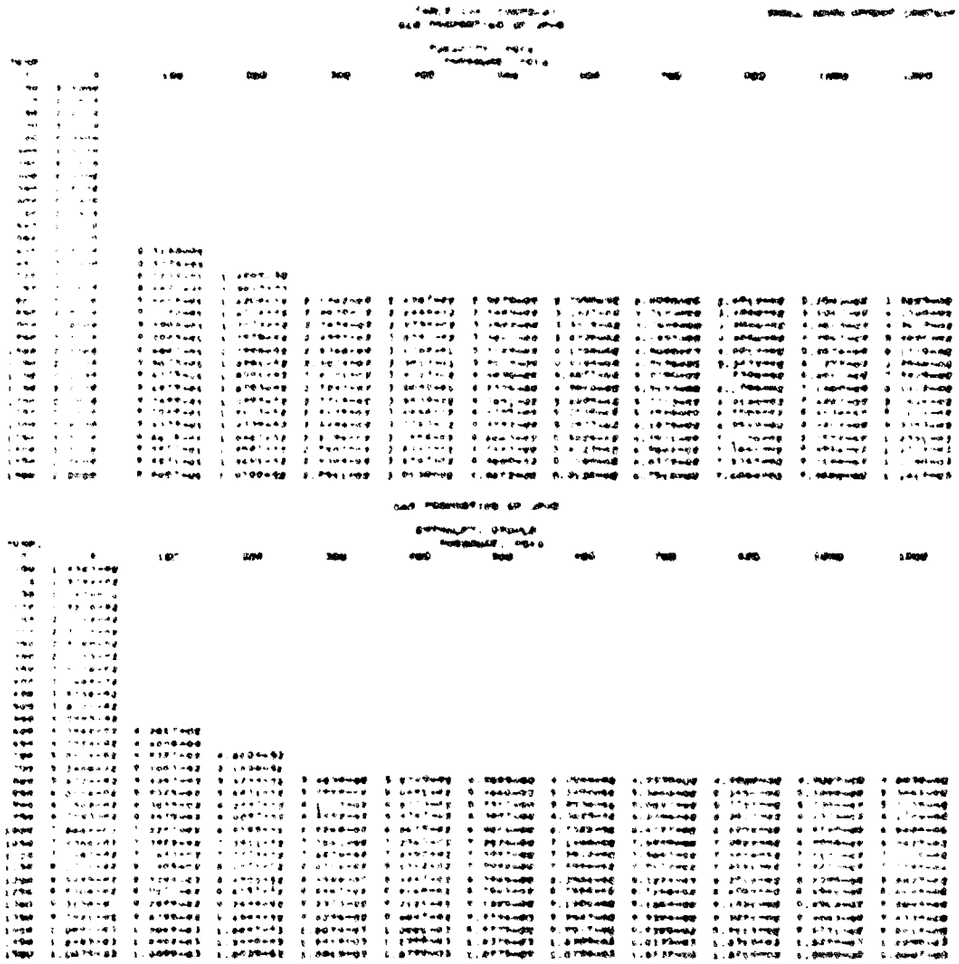


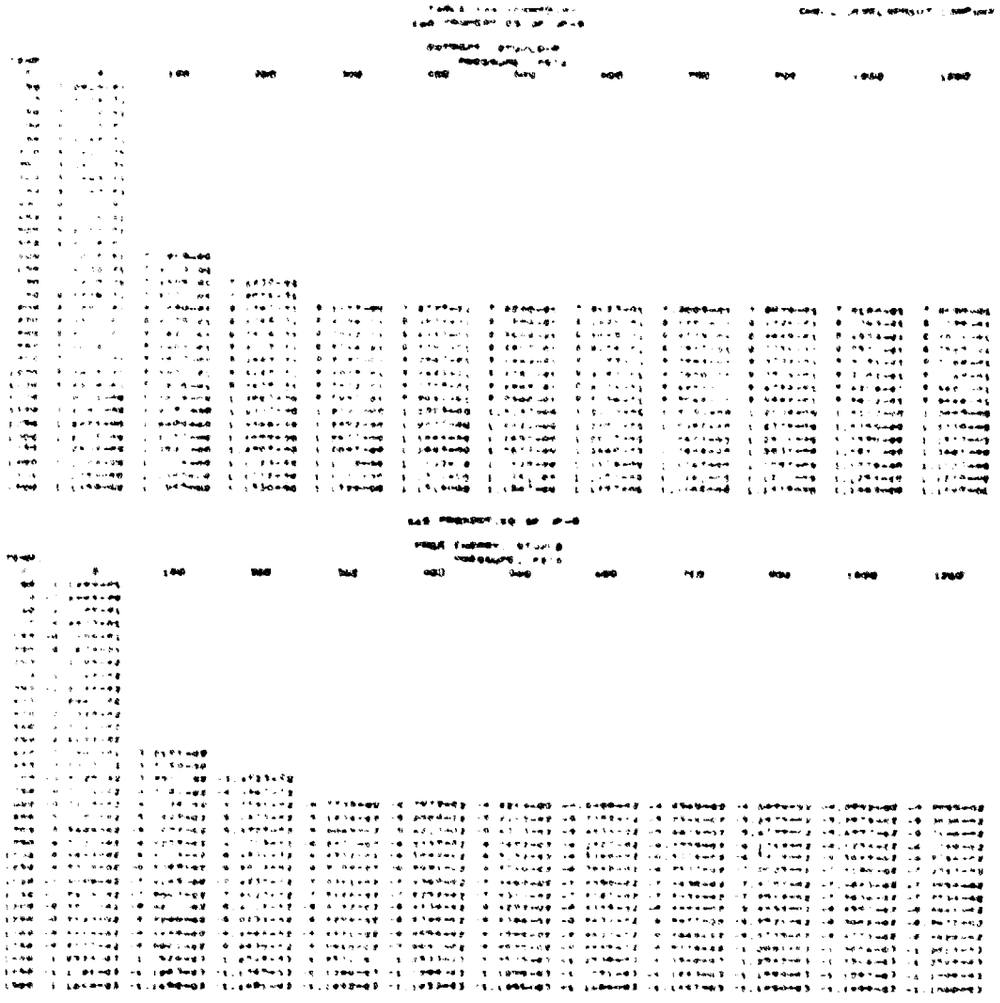


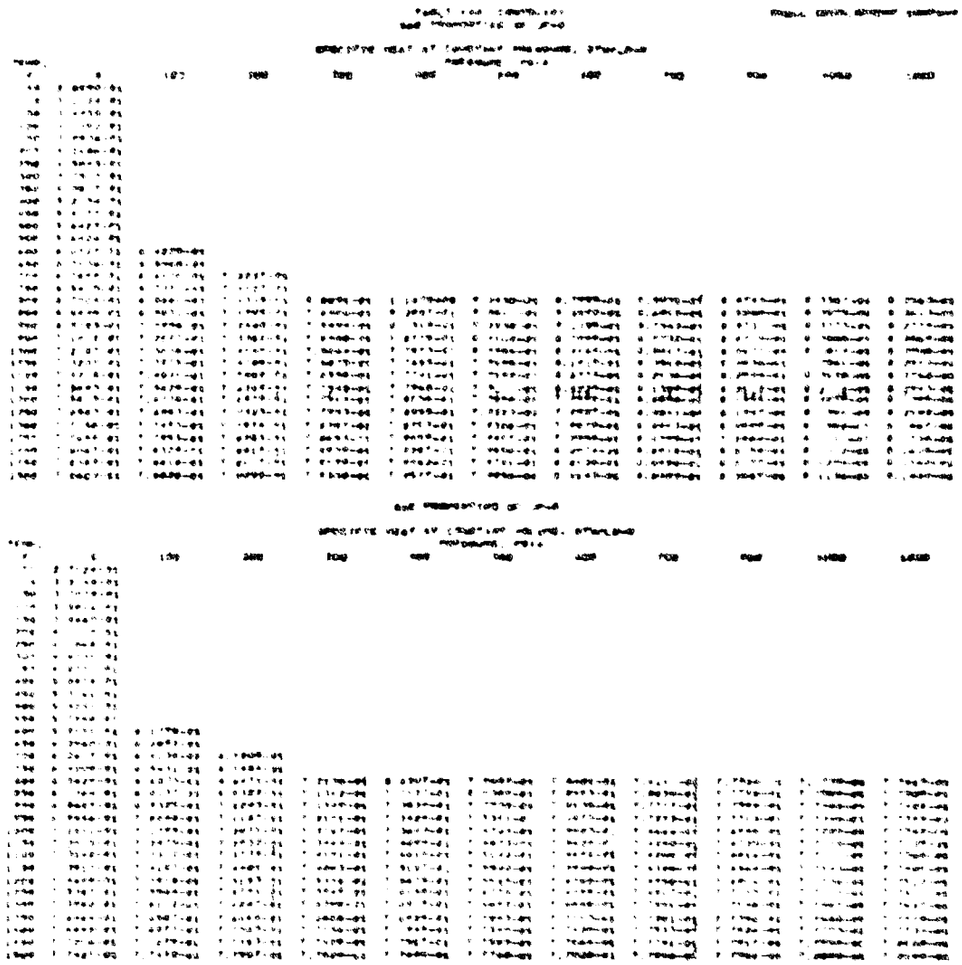


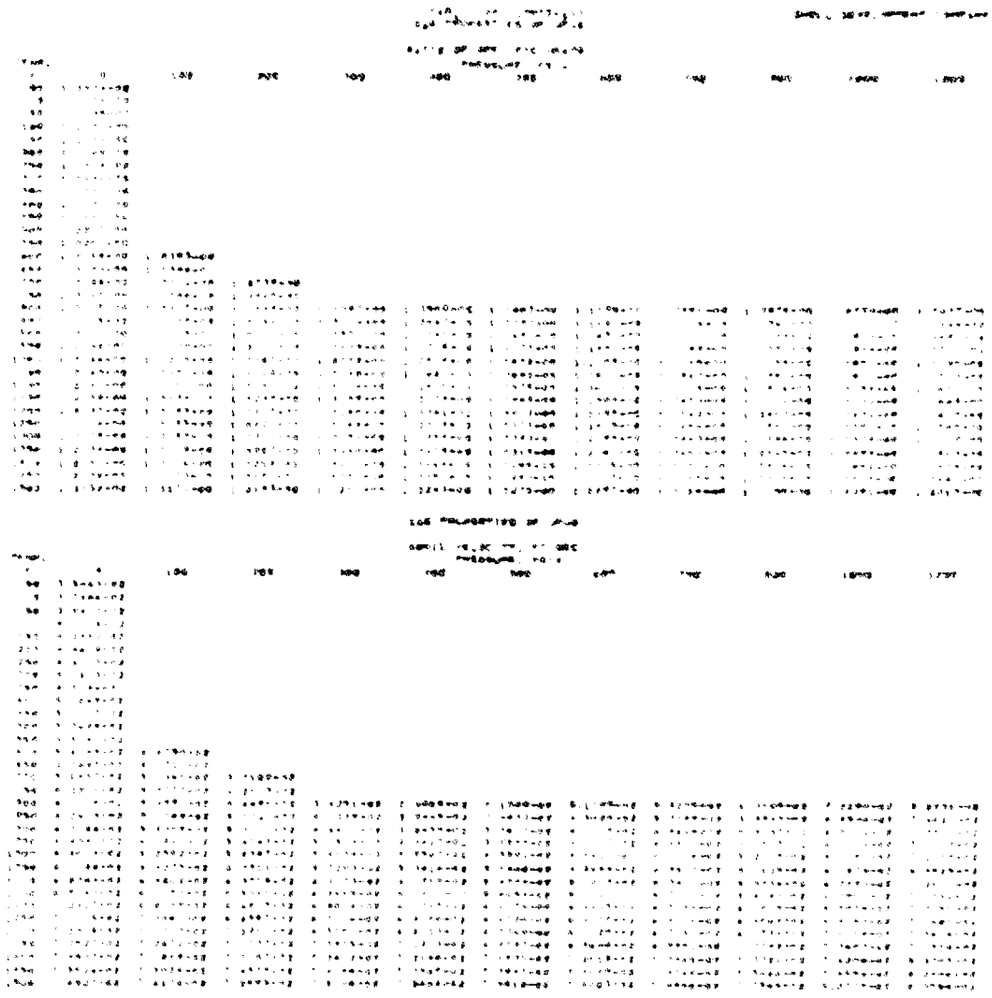


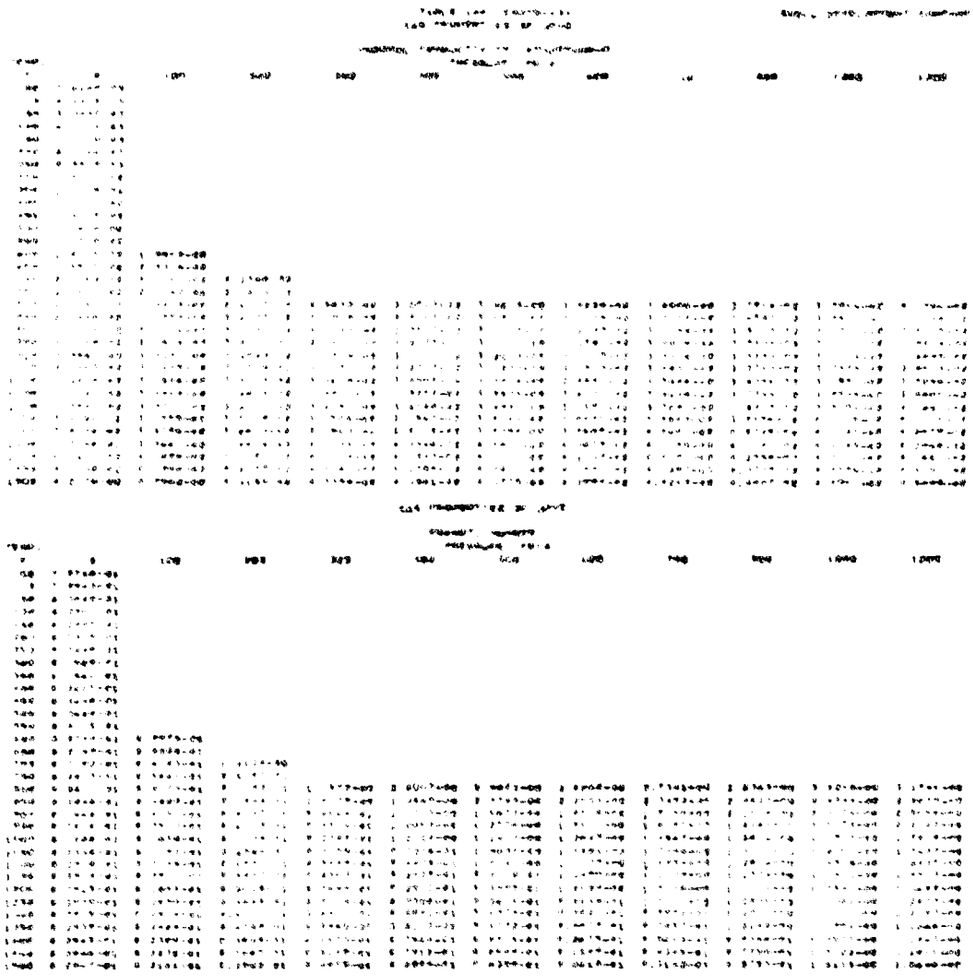












[redacted]

Preliminary Analytical and Physical Property Data

Following are typical analytical data and calculated physical property information based on a variety of methods. Since only a limited number of samples of [redacted] have been prepared, the consistency of the data from batch to batch has not been established. Also, pending larger scale preparations, we have not independently calculated the effect of temperature and pressure, outside the normal range, on various liquid and gaseous properties of interest. Instead we have applied corrections to the values calculated for [redacted] itself, as given in the citation above, as deemed advisable.

The magnitudes of the correction factors involved are generally not large and we believe the data can be used without serious error. Improved information will be supplied as soon as it is available.

[illegible]

[illegible]

	Typical	Test
Gravity, deg API	[illegible]	ASTM [illegible]
Specific gravity	[illegible]	
Refractive index, n_D^{20}	[illegible]	ASTM [illegible]
Color	[illegible]	
Distillation temperature, °F		ASTM [illegible]
Initial boiling point	[illegible]	
10% Evaporated	[illegible]	
20% Evaporated	[illegible]	
50% Evaporated	[illegible]	
90% Evaporated	[illegible]	
End Point	[illegible]	
Loss, %	[illegible]	
Residue, %	0.9	
Sulfur, %w	0.0001	ASTM [illegible]
Mercaptan sulfur, %w	<0.001	ASTM [illegible]
		[illegible]
Existent Gum, mg per 100 ml	1	ASTM [illegible]
Freezing point, F	[illegible] a)	ASTM [illegible]
		[illegible]
Boiling point, °F	[illegible]	ASTM [illegible]
Net heat of combustion		ASTM [illegible]
Btu/lb	17,590	
Btu/gal	123,300	
Aromatic content, %v	[illegible]	ASTM [illegible]
Olefin content, %v	1	[illegible]
Copper strip corrosion	1A	ASTM [illegible]
Viscosity, cs, at 100°F	13	ASTM [illegible]
0°F	215	
-30°F	1200	
Flash point, F	130	ASTM [illegible]
Vapor pressure, psia at 300°F	3.5	
psia at 500°F	22	
Thermal stability, 5 hr	[illegible] b)	CRC Modified
Pressure change, in. Hg	[illegible]	Standard Laser
Preheater deposit rating	2-1/2 b)	
Smoke point	[illegible]	[illegible]
Carbon/hydrogen ratio	[illegible]	Calculated
Critical temperature, F	[illegible]	API [illegible]
Critical pressure, psia	[illegible]	API [illegible]
Heat of formation, H_f, Btu/lb	[illegible]	
Molecular weight	[illegible]	

a) Saturated fluid becomes [illegible], then a [illegible], [illegible] samples have formed crystals at temperatures of about [illegible] and below.

b) CRC-ASTM [illegible] coker.

c) ASTM D86 point corrected as per API Figure 3A1.1.

Table 146. LIQUID PROPERTIES OF [illegible] AT SATURATION PRESSURE

Temp, °F	Density, lb/ft³	Viscosity,[a] lb/ft-hr	Thermal Conductivity, Btu/ft-hr-°F	Heat Capacity, Btu/lb-°F	Enthalpy, Btu/lb	Heat of vaporization, Btu/lb	Vapor Pressure, psia
-60	70.8	22000.	0.098	0.217	-14.5	151.9	0.0000
0	69.3	512.	0.096	0.257	0.0	146.5	0.0000
100	66.6	35.7	0.093	0.342	29.0	142.3	0.0011
200	63.8	8.78	0.090	0.387	64.5	137.7	0.0045
300	60.9	3.12	0.085	0.452	106.4	128.4	0.040
400	57.8	1.41	0.079	0.507	154.6	120.4	2.97
500	54.5	0.752	0.072	0.559	207.7	111.5	11.50
600	50.9	0.432	0.064	0.606	266.0	101.3	32.9
700	46.7	0.341	0.057	0.651	328.8	88.9	76.2
800	41.7	0.258	0.048	0.702	396.3	72.9	153.0
900	34.2	0.155	0.040	0.818	470.9	46.8	278.8

a) To convert to cs multiply by $\frac{25.8}{\text{density}}$.

[illegible]

Temp. °F	Pressure, [illegible]										
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]										
[illegible]			[illegible]								
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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0	[illegible]										
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*) The reference state is the liquid at [illegible] pressure and [illegible] °F

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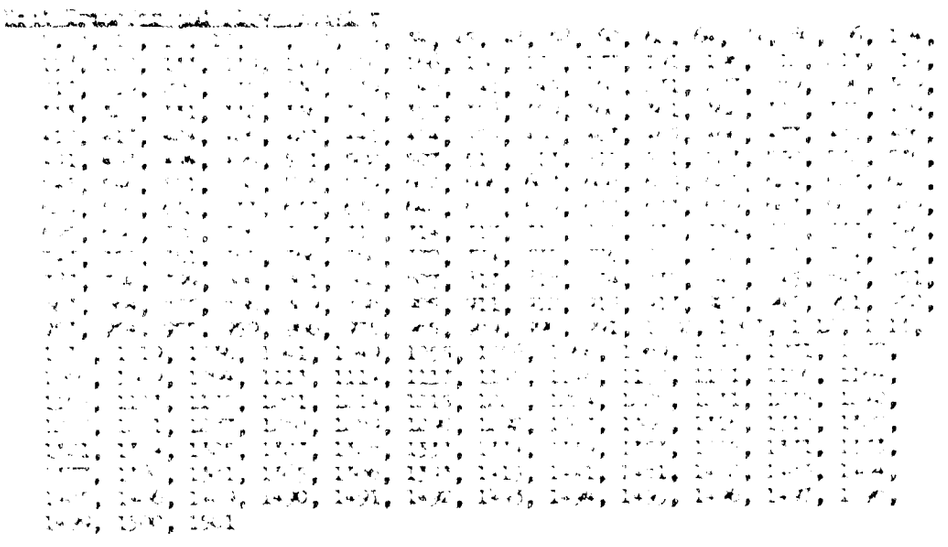

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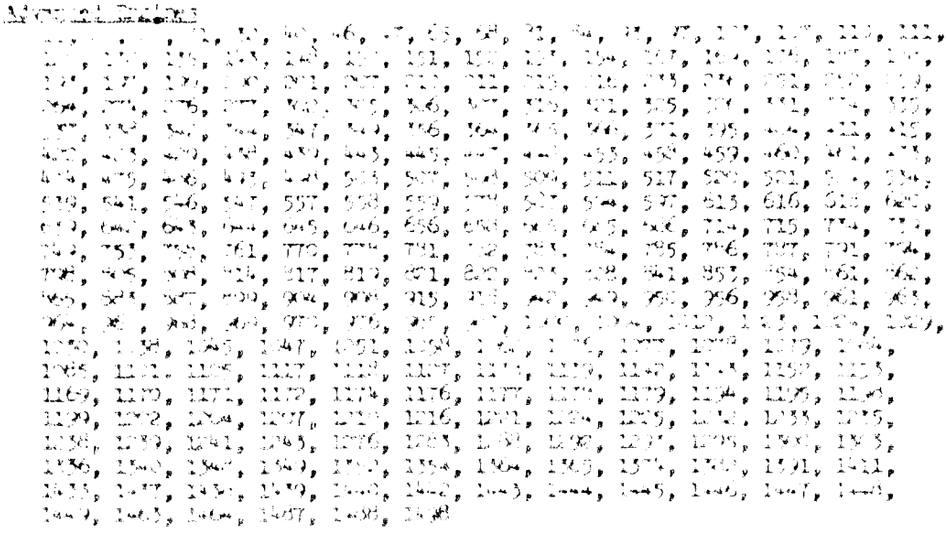

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DOCUMENT CONTROL DATA - R&D

Shell Development Company,
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Unclassified

N/A

VAPORIZING AND ENDOTHERMIC FUELS FOR ADVANCED ENGINE APPLICATION.
Part III. Studies of Thermal and Catalytic Reactions, Thermal Stabilities,
and Combustion Properties of Hydrocarbon Fuels

Final Report - June 1966-September 1966

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February 1967	562	58
AF 33(615)3589 30-3 Task No. 304809	AFAPL-TR-67-114 Part III, Vols I and II	

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The feasibility of utilizing hydrocarbon fuels for high speed air craft depends upon the endothermic and enthalpic capacity of the hydrocarbons, and the combustion properties of the products. At Mach 8 a supersonic combustion ram jet engine would require about 1900 Btu of cooling per pound of fuel. The enthalpic capacity of hydrocarbons can be augmented by thermal and catalytic reactions. These have been studied. The rate of thermal cracking can be accelerated by means of additives. The rate of dehydrogenation of naphthenes, a strongly endothermic reaction, can be increased by the use of improved catalysts based on platinum - alumina. The stabilities of such catalysts are inversely proportional to the pore size of the support and are affected by composition. Dispersed catalysts have some advantages over bed type catalysts and some indications of possible success have been observed. About 1/3 of the 850 catalysts developed for naphthene dehydrogenation has been more active than the standard laboratory catalyst, although none is orders of magnitude better. Wall catalysts have the advantage of low pressure drop and are showing efficiency benefits also. Calculations show that diffusion limitations can be avoided if the coating thickness is no more than about 3 mils thick. Satisfactory operation with both improved bed catalysts and wall catalysts has been demonstrated in the fuel system simulator with both methylcyclohexane and Decalin. Heat transfer studies have been carried out with MCH, Decalin, [redacted]-8 and JP-7 fuel in small diameter test sections under heat fluxes up to 8 x 10 Btu per hour per square foot. Studies on the effect of high temperatures on the thermal stability of various fuels have been continued with emphasis on methods of measuring deposits on tube surfaces. Combustion and electron back scattering are the methods of present choice and an instrument based on the latter principle has been designed. Mathematical models are being devised to represent the various portions of an endothermic fuel system with present emphasis on the development of heat transfer correlations and a model for the dehydrogenation of Decalin. Physical properties for Decalin and JP-6 are included. Calculation of the rate of oxidation of normal octane and [redacted]-8 from shock tube studies indicate similar rates of reaction and temperature coefficients.

DD Form 1473

Unclassified
Security Classification

KEY WORDS

Endothermic fuels
Advanced fuel systems
High density fuels
Fuel properties
Supersonic combustion
Chemical tube
Catalytic reaction
Dehydrogenation
Catalysts
Wall catalysts
Reaction kinetics
Kinetic models
heat sink
Thermal reaction
Hydrocarbon fuels
Literature survey
Thermal stability
Deposit measurement